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Client/Sponsor of project

Department of Energy, Mines and Resources of Canada/Canmet

Work carried out by

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Det norske Veritas
Industrial and Offshore Division

POSTAL ADDRESS: P.O.BOX 300, 1322 HØVIK, NORWAY
TELEPHONE: +47(02) 12 99 55
CABLE ADDRESS: VERITAS, OSLO
TELEX: 16 192 VERIT N

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Work carried out by
G.H. Eide, K.O. Vilpponen, et.al.

Date	
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Approved by
Jan Erik Hagen

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J.B. Gilmour

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Summary

This report reviews material requirements to structural steels and weldments in mobile and fixed offshore platforms. The review is based on regulatory guidelines set forth by U.S. Geological Surveys, The Norwegian Petroleum Directorate, The Department of Energy UK, as well as on rules issued by the Classification Societies (DnV, Lloyds Register, ABS, Bureau Veritas, Germanische Lloyds). These guidelines and rules are compared with current offshore practice as reflected by API' recommendations and owners specifications. Application of these requirements to Arctic environments is commented upon.

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APPENDIX A STATEMENT OF WORK

ABBREVIATIONS:

NPD = Norwegian Petroleum Directorate

DoE = Department of Energy (United Kingdom)
U.S.G.S. = United States Geoligical Surveys

DnV = Det norske Veritas

BV = Bureau Veritas
LR = Lloyd Register of Shipping
ABS = American Bureau of Shipping
GL = Germanischer Lloyds

API = American Petroleum Institute
AWS = American Welding Society
ASME = American Society of Mechanical Engineers

C.A. = Certifying Authority (in U.K.)

CV = Charpy V-notch toughness
CVL = Charpy V-notch longitudinal direction
CVT = Charpy V-notch transverse direction

HV = Hardness measured by Vickers method
HV5 = Hardness (Vickers) measured with 5 kg load

CE = Carbon Equivalent calculated by the formula

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

R_{EH} = Minimum yield strength
R_M = Ultimate tensile strength

0. ACKNOWLEDGEMENT

This report includes brief review/description of four recently designed and constructed offshore platforms. The structures are:

- North Cormorant, operated by Shell Expro, UK
- Maureen, operated by Phillips Petroleum Company, Europe & Africa
- T2005, designed by Compagnie Fransaice d'Entreprises Metallique, U.S.A.
- Pacesetter, designed by Fried + Goldman, U.S.A.

Det norske Veritas appreciate the mentioned companies' permissions to use their platforms as case structures in this review.

Opinions expressed in this report are those of Det norske Veritas and should not be considered to represent the position of Canmet or of the Canadian Department of Energy Mines and Resources.

1. INTRODUCTION

Large and complex offshore structures are required when exploiting hydrocarbon resources offshore. During the past years significant experience has been gained in particular from offshore constructions in the North Sea. Increasing water depths, more severe weather conditions as exploitation moves northwards and increasing safety requirements have lead to increasing demands on material qualities and properties. Although North Sea platforms represent only 5% of world total, the amount of steel used represents over 20% and investments over 40%.

The aim of this study is to review and evaluate what property requirements are imposed on steel materials and fabrication by governmental bodies, classification societies/certifying authorities and owners. The study also describes the typical application of steels in the important members in different offshore structures. Particular attention is given to conditions and factors considered of signifance for selection of structural materials. Chapters 2-7 will describe rules and regulations whereas chapter 8 concentrates on current offshore practice highlighted by some selected "case" structures.

Requirements for quality control systems and testing during manufacture of materials and fabrication of the structures are not covered by this review.

1.1 Common types of offshore structures

Fixed structures

Jacket platform: The most conventional platform is of the type shown in Fig. 1. This consist of a piled jacket template with a steel deck supporting equipment modules, cranes, flare and derrick as required. The jacket is constructed of a framework of tubulars secured to the seabed by long piles driven through or fixed to the jacket's vertical legs. The weight of the structure depends strongly on the environmental conditions and the water depth, and may for a North Sea structure be of the order of 10000 tons in water depth about 100 m. The braces are generally from 50 to 80 cm in diameter, the vertical leg tubulars are up to 3 m in diameter while the wall thickness vary from 20 to 90 mm. Greater dimensions are however not unusual.

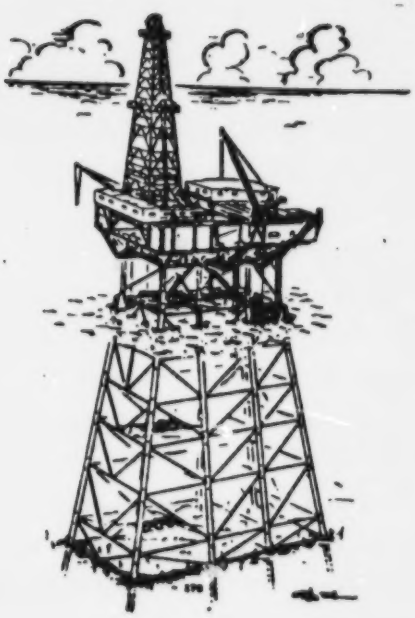


Fig. 1 Jacket structure

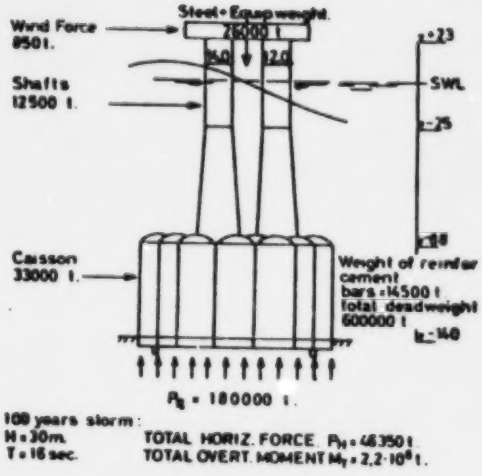


Fig. 2 Gravity structure

Gravity platform: Gravity structures usually have a concrete substructure with a steel deck. These huge structures have normally the function of drilling, production and quarters combined on the same platform. Therefore the deck structure with modules may be much greater and heavier than on conventional jackets. deck and module weight may vary from 25 000 to 50 000 tons.

There has also been designed and is under construction steel gravity structures, e.g. the Maureen platform, but also deck support frames of reinforced concrete beams have been used, e.g. Frigg CDP-1.

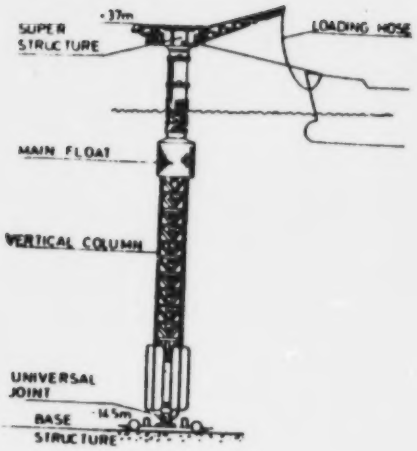


Fig. 3 Offshore loading platform

Offshore (oil) loading facilities: A bottom supported oil loading platform as used in great water depths in the North Sea is shown in Fig. 3. This structure has a steel cased, concrete filled gravity base, vertical column on the top of a universal joint and a revolving superstructure. The buoyancy of a large floatation tank keeps the platform upright.

In one case the column has been designed of concrete.

There are also installed loading buoys which are kept in position with anchor chains. They are more typical for use in shallow water depths where weather conditions are less severe.

So far offshore loading is only used for oil, while the gas has to be transported through pipelines, reinjected in the reservoir or flared off.

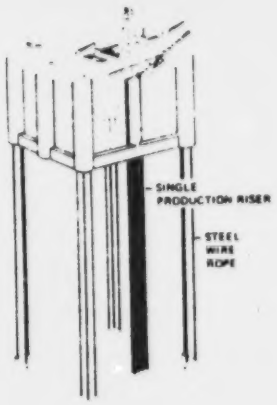
Tension leg platform: A tension leg platform is a floating structure, vertically moored. Forces and moments caused by the environment are mainly taken as tension forces in the tension members. The floating structure is based on the semisubmersible principle. The excess buoyancy of the platform maintains the tension member in tension, which in turn keeps the platform on station.

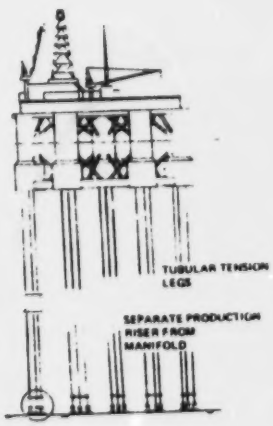
A number of tension leg concepts are now in the stage of detailed engineering and examination. Some of the concepts indicating different system solutions are shown.

Wellheads can be located either on the platform and then utilize normal well completion or on the sea floor with subsea completion.

These type of platforms will be used for great water depths (> 200 m) and have to utilized extra high strength materials. They represent new challenges as their application in a corrosive environment under fatigue actions and in very thick section find rather little support in past experience. Some concepts are shown below.

Fixed Floating Structures





Mobile structures

Mobile offshore units are principally of three types:

- Column stabilized units:
  These are platforms supported by lower displacement type hulls by means of columns. The unit may float (semisubmersible) or rest on the bottom (submersible).

- Self elevating units (jack ups):
  These are units that rest on the sea bottom by means of legs, which can be lifted with mechanical or hydraulic jacking devices. The deck structure acts as a hull during transportation.

- Drilling ships:
  Drilling ships are except for their drilling arrangement in principal identical to ships, and are therefore not further considered in this review.

Typical lay-out for the two former are shown in Fig. 4.

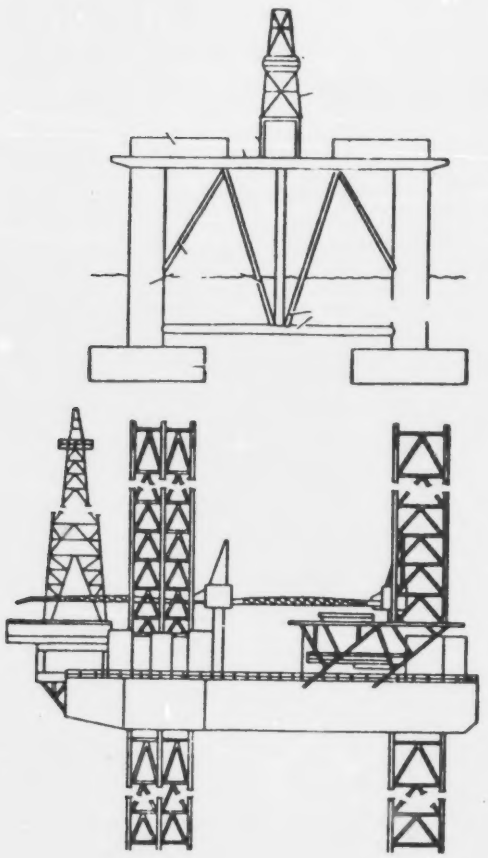


Fig. 4a Column stabilized unit

Fig. 4b Self elevating unit

1.2 Principal design approach for mobile units versus fixed structures

Traditionally mobile units have been designed and evaluated on similar principles as used for ships. Rules for mobile units in fact refer extensively to material requirements in corresponding ship rules. Mobil units may operate in quite different areas. Thus their design premises in terms of loads and period are not as easily defined as for fixed structures. To simplify material requirements, the designation "world wide class or services" has been introduced, which means that the materials are to be selected on the basis of a minimum design temperature of minus 15°C. This does however not imply that the mobile unit can operate constantly in such areas, but that they may be used there for limited periods.

The requirements on materials and material properties imposed by governmental bodies, certifying authorities and classification societies are often different as concerns fixed vs mobile offshore units. A fixed unit cannot be subject to inspection and repairs as easily as a mobile unit, and this aspect tends to be reflected in the corresponding design approaches.

Rules for fixed offshore structures are generally based on another philosopy where the design is to take into account that the platform shall be fit for service on the same location throughout the whole life. This is typically specified to be from 20 to 30 years for North Sea platforms.

1.3 Environmental Conditions - North Sea vs. other areas

The Table 1 below shows typical conditions used as a design basis for fixed offshore units in the North Sea.

The conditions in the considered arctic areas are comparable with North Sea conditions with respect to wave heights, astronomical tides and wind speeds. However, the greater differences may be encountered concerning minimum air temperatures, and in particular the ice conditions. In the North Sea, design of offshore structures does not require taking into account ice movement. Increased loads due to snow and ice have also been negligible for the present North Sea installations, i.e. south of 62° north. In contrast off the coast of Labrador well below 60° latitude, air temperature in winter may be well below 0°C and the sea covered with ice. In Baffin Bay and Beaufort Sea, the January temperatures will be below minus 30°C. However, summer temperatures can be comparable to North Sea conditions. Accordingly material/selection will probably follow similar approach for the submerged parts of the structures but may have to be reconsidered for parts in the splash and atmospheric zones.

TABLE 1 NORTH SEA ENVIRONMENTAL DESIGN CRITERIA

Basis 100 years return period	EKOFISK AREA	FRIGG AREA	BRENT AREA	ALASKA ARCTIC ISLANDS CANADA NORTH COASTAL 1)	GRAND BANKS HIBERNIA 2)	BEAUFORT SEA 3)	GULF of MEXICO 1)
Water depth (M.L.W)	70m	98m	142m	up to 450 m	80	50	70 (Louisiana)
Wave height	24m	28m	30,5m	~ 15m-30m	20		15 (10 year)
Wave period	15s	15s	17s				13
Astronomical tide	1m	1,7m		~ 1,2m		1,2	
Storm tide	0,7m	0,6m					
Sustained storm wind	56m/s	55m/s	61m/s	~ 60	50		
Gust wind	68m/s	66m/s	78m/s	~ 70m/s			50
Current (storm wind + tidal)							
Surface	0,8m/s	1,35m/s	1,43m/s				~0,9
Bottom	0	0,3m/s	0,24m/s				~0,2
Airgap (wave crest clearance)	2,3m	2,95m					
Marine growth (on radius)		+3,5m to -1,5m:6,5cm -1,5m to -85m: 10cm -8,5m to -15m: 6,5cm	-				
Ice conditions	none	none	none	ice movement icebergs	ice	ice	none
Temperature minimum °C	approximately -10			-50	< 0	<-30	humid, hot +15

1) These columns are included to indicate extreme weather conditions in arctic areas and in the Gulf of Mexico.

2) Oil and Gas Journal, Feb. 1982 (Ocean Ranger accident).

3) Oil and Gas Journal, Dec. 1981.

It is only natural, however, that other requirements will be considered for materials for arctic offshore structures. In particular weldability and fracture toughness properties will have to be evaluated in context with the weather conditions and the possibilities, if any, for in-service repairs.

1.4 Reviewed reference documents

Offshore installations are today in general subject to some kind of national regulations both for design and operation. These regulations may vary significantly in scope and conditions depending on the country and the traditions.

Such regulations are worked out to cover both exploration and production activities, and address the principal aspects which have to be taken into account, but without imposing too detailed technical requirements. Although the regulations may apply to both mobile units and fixed structures, it is common practice that the governmental bodies may for mobile units accept a "class certificate" issued by a recognized Classification Society, or by an appointed Certifying Authority or Verification Agency as it may be designated. The class certificate is then to take into account special applicable national requirements.

Therefore in this review regulatory requirements concerning material and construction requirements for mobile units, are generally taken to be those of the various Classification Societies. For fixed structures the following regulations have been specially considered (as requested by DoEMR/Canada).

a) The Norwegian Petroleum Directorate (NPD) : Regulations for the structural design of steel structures on the Norwegian continental shelf (1977)

b) Department of Energy, U.K. (DoE) : Regulations for the design and construction of offshore installations (1977)

c) United States Geological Surveys (U.S.G.S.) : Requirements for verifying the structural integrity of OCS platforms (1980)

The following Classification Societies' rules and recommendations form a basic element for this study.

a) Det norske Veritas (DnV), Rules for Offshore Structures 1977
, Rules for Mobile Offshore Units 1981
b) Bureau Veritas (BV) , Rules for Offshore Platforms 1975
c) Germanischer Lloyd (GL), Rules for Offshore Installations, vol I 1976
d) Lloyd's Register (LR) , Rules for Mobile Offshore Units 1972
e) American Bureau of Shipping (ABS) , Rules for Mobile Offshore Drilling Units 1980
f) Nippon Kaiji Kyokai , Mobile Offshore Units, Part B and P 1978

Classification Societies publish guidance and rules which is detailed and forms a the basis for classification and certification/verification activities.

It is important to realize that such rules are to be considered as basic requirements. Alternative requirements may be proposed and accepted. When comparing the different requirements, due consideration must be given to the fact that rules often reflect the individual experience of each society and may accordingly deviate in particular instances.

References will also be made to:

g) American Petroleum Institute (API), RP-2A "Planning, designing and constructing fixed offshore platforms (1981)

RP-2A gives recommendations onmaterials selection and fabrication of offshore structures.

Other documents of importance are:

h) American Welding Society (AWS), Structural Welding Code AWS D1.1
i) American Society for Mechanical Engineers (ASME), "Codes for Pressure Vessels (Sec. V, VIII; IX) 1980

In addition to the national regulations, rules, recommended practice etc. there may be issued project specifications by the owner or operators. Such specifications may be very brief for mobile units as concern the materials aspect, in fact only covered by reference to the selected Classification Society, while they are often very comprehensive for fixed structures.

One reason for this is probably the fact that investment and the cost of operation and maintenance of fixed structures are magnitudes greater than for mobile units, and thus justify very detailed project specifications.

Project specifications in most cases comply with minimum requirements imposed by classification societies. In practice, however, project material specifications can imply restrictions well beyond that of classification society rules. It is common practice that operator companies have their own approval procedures and standard company specifications. These may then also include prequalification testing of materials and contractors, even if they have the approval of one or more Classification Societies.

1.5 Design versus service temperatures

The operating temperature has profound influence on material selection as it may significantly affect the fracture toughness properties.

It is therefore essential how the testing temperature is related to the minimum design or service temperatures, since these definitions may vary.

References	Parameter used	Definition
NPD DnV	Minimum design temperature T_D	The lowest monthly mean temperature minus 5°C for the zone (air-splash-submerged) in question
DoE	Minimum design temperature	Specified as -10°C for air splash zone south of 54° N -6°C north of 54° N, while 0°C for seawater i.e. taken as lowest daily temperature
USGS ABS API	Minimum service temperature expected in the operational environment	o At or below waterline: The lowest average, daily water temperature applicable to the particular depth o Above waterline: Lowest average daily atmospheric temperature
German Lloyds	Lowest service temperature	Lowest anticipated air temperature and -2°C for sea water unless other temperatures are expressly specified
Bureau Veritas	Minimum design temperature	Splash/air zone: 5°C below the lowest monthly mean temperature Sea water: Minimum monthly mean temperature, however as max -5°C unless otherwise documented

Normally long periods of temperature measurements are to be the basis for determination of the relevant parameters, and the records are to be representative for the area the platform is expected to operate or planned to be installed.

2. MATERIAL SPECIFICATION - BASIC CONTENT

2.1 General

A material specification will normally include the following items to a lesser or greater degree.

- o Material reference standard
- o Designation and application of various steel types
- o Steel making process
- o Deoxidation practice
- o Ladle treatments
- o Casting methods
- o Supply conditions - heat treatment requirements
- o Chemical composition
- o Mechanical properties (strength, ductility, notch toughness, strain ageing resistance)
- o Soundness
- o Dimensional tolerances
- o Delivery testing
- o Quality control systems
- o Documentation
- o Certification

The specifications are normally either worked out by the designer or consultants, and approved by the operator and the Classification Society. The specifications may cover rolled plates, seamless tubulars, forgings, castings, bolts and nuts etc.

2.2 Material reference standard

For mobile units the reference standard would be the rules of the involved Classification Society. Every Classification Society has their designations for various steel grades which represent a complete basis for ordering and manufacturing of the steel. The designations are those used for ship/hull materials.

In practice the major Classification Societies have worked out unified material requirements. Variations in the same steel grade would be minor.

The unified rules for ship grade steel are summarized in Table 2a. Tables 2b and 2c give extracts of DnV-Rules for hull structural steels.

Table 2 a Normal Strength Hull Steels (general)

Grade	A	B	D	E
Deoxidation	Any method	Any method except rimmed steel		Fully killed fine grain practice
Chemical composition, %				
Carbon, max.	0,23	0,21	0,21	0,18
Manganese, min.	-	0,60	0,60	0,70
Phosphorus, max.	.04	.04	.04	.04
Sulphur, max.	.04	.04	.04	.04
Tensile test				
Tensile strength	400 - 490 MPa			
Yield stress, min.	235 MPa			
Elongation, min.	22%			
Impact test temperature	Not required	0°C	-10°C (-20°C)	-40°C

Table 2 b Requirements to normal strength steel (DnV)

1. Grade	NVA	NVB	NVD	NVE
2. Deoxidation	Any method (for rimmed steel, see Note [1])	Any method except rimmed steel		Fully killed, fine grain practice
3. Chemical composition (ladle analysis)	Carbon plus 1/6 of the manganese content is not to exceed 0,40 %			
C (max.)	0.23[2]	0,21	0,21	0,18
Mn (min.)	2,5 xC	0,80[4])	0,60	0,70
Si	0,35 max.			0,10 —0,35
P (max.)	0,040			0,040
S (max.)	0,040			0,040
Al (min. acid soluble)				0,015[5])
4. Tensile test				
Tensile strength (N/mm²)	400—490 [6])			
Yield stress (N/mm²)	235 min.[3])			
Elongation % on 5,65 $\sqrt{S_o}$	22 min.[7])			
5. Impact test				
Test temperature (° C)		0	— 10[8])	For plates each piece to be tested — 40
Average energy (J) min.		27 (L) 20 (T)	27 (L) 20 (T)	27 (L) 20 (T)
6. Heat treatment			Normalized over 25 mm When fine grain treated over 35 mm	Normalized

1) For grade NVA up to 12.5 mm in thickness inclusive, rimmed steel may be accepted subject to special agreement with the Society.

2) For grade NVA up to 12.5 mm in thickness inclusive, subject to special agreement with the Society, a higher maximum carbon content may be accepted and the minimum manganese content may be less than 2.5 times the carbon content.

3) For grade NVA up to 25 mm thickness, the minimum yield stress may be 230 N/mm². For grade NVA greater than 25 mm in thickness, the minimum yield stress may be 220 N/mm².

4) For grade NVB, when the silicon content is 0.10 — or more (killed steel), the minimum manganese content may be reduced to 0.60%.

5) For grade NVE, the total aluminium content may be determined instead of the acid soluble content. In such a case the total aluminium content is to be not less than 0.020%. An upper limit for the aluminium content may be required by the Society. Other grain refiners may be used upon special approval of the Society.

6) For all thicknesses of Grade NVA shapes the upper limit of the specified tensile strength may be exceeded at the Society's discretion.

7) The minimum elongation for the flat specimen with a width of 25 mm and gauge length of 200 mm is to comply with the following requirements:

Thickness t (mm)							
t ≤ 5	5 < t ≤ 10	10 < t ≤ 15	15 < t ≤ 20	20 < t ≤ 25	25 < t ≤ 30	30 < t ≤ 35	35 < t ≤ 50
14 %	16 %	17 %	18 %	19 %	20 %	21 %	22 %

8) For special applications impact testing at - 20°C may be required. When tested at - 20°C, the steel grade designation NVDS is to be used.

Table 2 c Mechanical properties, deoxidation and grain refining treatment for high strength steel (DnV)

Designation		NVA27S	NVD27S	NVE27S	NVA32	NVD32	NVF32	NVA36	NVD36	NVE36	NVA40S	NVD40S	NVE40S
Deoxidation		semi-killed or killed	semi-killed or killed [1]	killed	killed [2]	killed [2]	killed	killed [2]	killed	killed	killed	killed	killed
Grain-refining treatment		—	— [1]	yes	—	yes	yes	—	yes	yes	yes	yes	yes
Tensile test	Tensile strength R_m N/mm²	400—510 [3]			440—590			490—620			530—650		
	Yield stress R_{eH} N/mm², min.	265			315			355			390		
	Elongation, % $L_o = 5{,}65\sqrt{S_o}$ (A_5) min.	22 [4]			22 [4]			21 [4]			20 [4]		
Impact test	Test temp. °C	—	— 20	— 40	0	— 20	— 40	0	— 20	— 40	0	— 20	— 40
	Impact energy, [6] J, min.	—	27 (L) / 20 (T)	27 (L) [5] / 20 (T)	31 (L) / 22 (T)	31 (L) / 22 (T)	31 (L) [5] / 22 (T)	34 (L) / 24 (T)	34 (L) / 24 (T)	34 (L) [5] / 24 (T)	39 (L) / 26 (T)	39 (L) / 26 (T)	39 (L) [5] / 26 (T)

1) For thicknesses 25.5 mm and above the steel is to be killed and fine-grain-treated unless otherwise agreed upon with the Society
2) Semi-killed steel may be accepted by agreement with the Society.
3) The specified maximum value may be 20 units higher for F quality.
4) For delivery testing using flat tensile test specimens (L_o = 200 mm), see Table
5) Every rolled piece is to be tested. For sections a reduced number of tests may be agreed upon
6) The test specimens may be cut with their axes either longitudinal (L) or transverse (T) to the final rolling direction at the option of the steelmaker

Elongation values for flat tensile specimens.

Grade \ Thickness	t ≤ 5	5 < t ≤ 10	10 < t ≤ 15	15 < t ≤ 20	20 < t ≤ 25	25 < t ≤ 35	t > 35
NV A27S NV D27S NV E27S	15 %	16 %	17 %	18 %	19 %	20 %	21 %
NV A32 NV D32 NV E32	15 %	16 %	17 %	18 %	19 %	20 %	21 %
NV A36 NV D36 NV E36	14 %	15 %	16 %	17 %	18 %	19 %	20 %
NV A40S NV D40S NV E40S	13 %	14 %	15 %	16 %	17 %	18 %	19 %

For fixed structures the practice of the operators has been to select steels in accordance with recognized standards such as DIN, BS, AFNOR, SIS, ASTM etc. and make modifications as found necessary.

Thus although a steel may be indicated as e.g. DIN 17100-St52-3N/type I on design drawings, the modifications are generally so many and significant, that the only valid reference left in the DIN-standard may be on strength, dimension, surface finish and testing frequency.

2.3 Structural steel types

Practically all structural materials for fixed structures are specified to be as normal strength steel and high strength carbon - manganese microalloyed steel. Normal strength steel is here defined as structural steel with $R_{EH} < 300$ MPa while a higher strength steel has R_{EH} 300 - 490 MPa and extra high strength steel has $R_{EH} > 500$ MPa.

In most cases the steels are normalized, but the trend in recent years seems to indicate that controlled rolled, thermomechanically treated as well as quenched and tempered steels are receiving increased attention. Extra high strength steels have commonly been used for jack-ups. Most structures are fabricated from rolled steel. There are also special design details where applications of steel castings and forgings are increasingly used. Only in very limited scale have alloy steels and Ni-alloys steels been used, and then mainly for jack-up rigs and corrosion protection in the splash zone respectively.

2.4 Classification and applications of structural steels

Government regulations only give general guidance to steel application, although special restrictions are being imposed on structural steel parts contributing significantly to the integrity of the whole structure.

The approach taken by most Classification Societies is a division into two or three categories of steel types according to the importance of the application.

The division shown in Table 3 is based on the DnV (Det norske Veritas) approach. The table shows also how the divisions applied by others are interpreted and what are the main applications and requirements of the steel types. It is emphasized that the intention is to have the design deciding the classification and use of various steel types.

TABLE 3 STEEL TYPES ACCORDING TO APPLICATIONS

CLASSIFICATION	FUNCTION	TYPICAL USE	PRINCIPAL REQUIREMENTS
SPECIAL STRUCTURAL STEEL (DnV) Class I (BV) Primary Components (Ger. Lloyd) Class A Steel (API RP-2A) Special Application Structures (ABS) Weld Class A members (USGS) Primary members (DoE)	MEMBERS ESSENTIAL/ CRITICAL FOR OVERALL INTEGRITY	can sections, deck to leg connections, cruciform joints of main girders main bracing in tubular structures intersection of lattice type leg structures	- transverse impact property requirements - limits on C, CE, impurities alloy elements - through thickness ductility - ultrasonic examination - each item tested - high strain ageing resistance
PRIMARY STRUCTURAL STEEL (DnV) Class II (BV) Secondary Components (Ger. Lloyd) Class B (API) Primary Application Structure (ABS) Weld Class B members (USGS) Secondary members (DoE)	MEMBERS PARTICIPATING IN OVERALL INTEGRITY/ CARRYING PRIMARY LOADS	jacket legs, piles, bracings, main girders and beams riser support structure module support jack house supporting structure of vertical columns	- longitudinal test - impact requirements - restriction on CE, alloy elements and impurities - heat testing - good cold forming ability
SECONDARY STRUCTURAL STEEL (DnV) Class III (BV) Class C (API) or no class Secondary Application Structure (ABS) Weld Class C members (USGS) Others (DoE)	OTHER LOCAL STRENGTH ELEMENTS	OTHER stiffeners deck floors internal framing upper platform decks equipment supports	- as per recognized steel standards for weldable grades - only impact testing in thicker sections (e.g. DnV fixed: 50 mm)

2.5 Steel making process

Table 4 indicates typical requirements that are imposed on the steel making process.

The governmental regulations restrict the process to be:

- open hearth
- electric furnace
- basic oxygen process

whereas the Classification Societies tend to leave open the possibility for new processes.

Due to the restrictions on impurities such as Phosphorus and Sulfur as well as Nitrogen, the Bessemer and Thomas processes are not regarded to be suitable, and are in fact directly forbidden by DoE, (UK).

The basis for steel making may both be pig iron or recycled scrap. The first route is often preferred to restrict the residual/tramp elements as Cu, Sn, Cr, Ni, As, Sb, etc. due to their influence on e.g. surface properties and temper embrittlement.

2.6 Deoxidation

It is common practice to require high strength steels to be fully killed while normal strength steel may in moderate thicknesses be semi-killed when used for non-critical members

In practice other requirements like impact properties would necessitate deoxidation to be undertaken.

Due to the increased use of continous casting, this aspect will be less significant in terms of specification as this method requires deoxidized steel.

2.7 Ladle treatments (other than deoxidation)

The referred regulations do not have specific conditions to e.g. fine grain treatment or vacuum degassing although it may be necessary for the steel maker to do so in order to meet property requirements.

TABLE 4 STEELMAKING REQUIREMENTS

	Steelmaking
NPD	open hearth electric furnace basic oxygen process
DoE	open hearth electric furnace basic oxygen process
US Geological Survey	According to recognized
API RP2	API/ASTM Standards
Bureau Veritas	open hearth electric furnace pure oxygen process any other equivalent
DnV	basic open hearth electric furnace LD-process or other approved process semi killed/fully killed steel
ABS German Lloyd Lloyds Register	According to ship rules requirements, i.e. similar to BV and DnV

The Classification Societies require that high strength steel for mobile units with guaranteed notch toughness below 0°C to be made by fine grain practice. Mostly Al, Nb are used as single or combined additions. V is also used to a great extent. Ti has only been used in few cases. The current limitations to micro alloying with these elements does not represent any practical restrictions to steel making except that certain operators have refused use of V-steels for their fixed structures.

The fabricators desire to have more weldable steels with very low C- and CE-values, has resulted in greater interest in Ti-N micro alloyed steels. It may thus be expected that other types of fine-grain treated steels will soon be applied. However the response of such steels to forming, welding and post weld heat treatment is not well known. Neither is the optimum nor the tolerable content of Ti-additions to such steels sufficiently investigated yet.

Ladle treatments for impurity and hydrogen control are rarely considered in regulations and rules, but are often included as a project requirement for steel for fixed structures. Injection metallurgy is now taking over where vacuum degassing often was necessary and earlier used. The latter is still prefered by some operators and steel makers if very high through thickness ductility is to be obtained without the risk for hydrogen flaking.

2.8 Casting methods

The method of steel casting, ingot or continuous, is left optional by regulations and classification societies. The latter do, however, tie their approval to the processing route for the steel, such that it would be considered an essential change normally requiring new approval testing for high quality grades.

Continuous casting is now generally replacing ingot casting, and may be used for rather thick plates.

2.9 Supply conditions - heat treatment

The referred regulations, except for DoE, give little guidance to acceptable supply conditions. Basically the steel may be supplied as rolled, controlled rolled, thermomechanically treated, normalized, quenched and tempered or age hardened if compatible with property requirements. DoE, however, requires that materials for important member shall be normalized, at thicknesses above 20 to 25 mm depending on strength level.

The Classification Societies do not restrict the options to any condition for material of moderate thicknesses and around 0°C min. service temperature. Normalizing, quenching and tempering are however the conditions for steels for demanding applications, thick sections or low temperatures. Controlled rolled steels are, subject to individual mill approval, often accepted to be comparable to fully normalized steel in certain thicknesses. This would, in DnV's case for fixed structures, also mean an evaluation of the application for the controlled rolled steels. They have inherited by processing more anisotropy of properties, and may thus not be suitable for through thickness loaded members, or in joints where a high risk of lamellar tearing exists.

The attitude in specifications is in line with this view. Steel makers are now offering e.g. controlled rolled sections in "anti-lamellar qualities", where both impurity level and Z-properties are guaranteed.

3. CHEMICAL COMPOSITION

3.1 Principal objectives

Construction of offshore platforms involves forming, welding and heat treatment operations etc., which all affect the characteristics of the materials. To ensure that the assembled structure has the expected properties and soundness such that it will sustain the predicted service loads and environment, it is necessary to control also the materials' chemical composition.

The principal objective is to ensure that the steel exhibits satisfactory formability and weldability when using common fabrication practices, as well as to allow in-service maintenance and repairs. Because the behaviour of a structural member is very often controlled by the local properties and soundess at the weld connections, weldability is an important consideration. By composition control it is possible to reduce the cracking risk and embrittlement due to forming, welding and stress relieving.

Accordingly both regulations and rules emphasize that the steels are to be of suitable composition. Regulations do it verbally or indirectly by reference to recognized material standards, while classification societies have all worked out detailed material specifications. The rules for mobile units, by their reference to requirements for hull/ship steels, give range limits. Rules for fixed structures tend to only give frame analyses. Project specifications may be much more detailed and comprehensive.

3.2 Carbon and carbon equivalent C-Mn and microalloyed steels

The most important element in steel is carbon since it affects transformation and weldability profoundly. Fig. 5 indicates typical limits concerning the maximum carbon content given in some rules and recognized standards. The allowed maximum content ranges between

$$C\ \% = 0{,}18 - 0{,}26$$

for normal and higher strength steels.

In practice, as will be seen later, project specifications may often be well below these values. The current trend is now to specify a max-value in the range 0,10 to 0,16 C for C-Mn microalloyed steel intended for fixed North Sea platforms.

Carbon equivalent defined as,

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

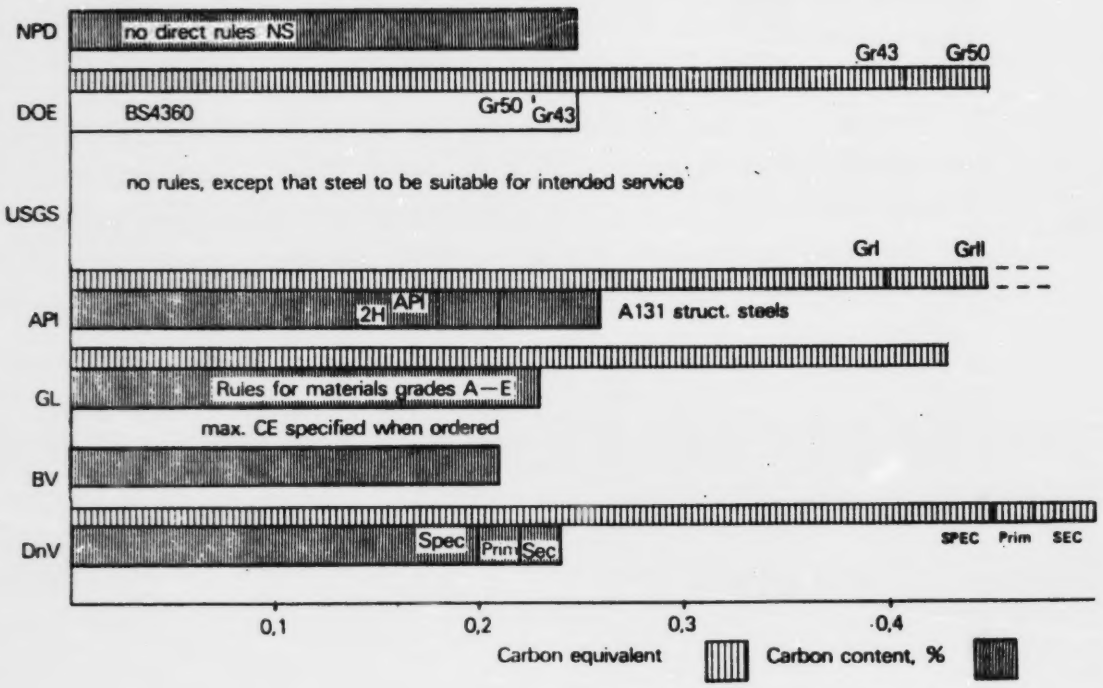
and is also shown on the graph. The limit from the regulations and rules tends to be in the range of,

$$CE = 0,4 - 0,5.$$

Current specification limits are often more restrictive from 0,38 to 0,43.

The higher C and CE-values are related to thicker sections where some composition allowances are necessary if the steel makers shall obtain required strengths.

FIG. 5 TYPICAL RESTRICTIONS ON CARBON EQUIVALENT AND CONTENT



3.3 Other elements

Table 5 shows a comparison of the maximum contents of main alloy elements allowed by different standards. Where several limits are given, they apply to different grades of steel.

Only in a few cases are restrictions imposed on minimum content. DnV rules for mobile units are based on ship rules, which in some cases may also define minimum contents, e.g. Si > 0.1% and Mn > 0.9%. Special emphasis is placed on sulfur and phosphorus that may adversely affect material properties, in particular the transverse toughness. In some cases specially low limits are applied as seen in the table. For thick sections the rule limit on sulfur content can be as low as 0.01% (German Lloyd).

In practice steels for critical applications with guaranteed transverse impact properties have sulfur contents in the range 0.003 - 0.010%. Most commercial C-Mn steels manufactured to ASTM/ISO/DIN/BS standards will comply with the requirements (table 4) on other alloy elements than for the C, S, and P contents. Typically project specifications for North Sea applications have referred to standards such as BS 4360 and DIN 17100 with due modifications, particularly on impurity content.

Elements that often seem to be unspecified are the interstitials Nitrogen and Boron the content of which should be carefully controlled. Even in small quantities they influence significantly to the ageing embrittlement and hardenability respectively. Modern project specifications may include these and other specific elements, or require the operators approval before additions are allowed.

TABLE 5 SPECIFICATION LIMIT FOR ALLOY AND IMPURITY CONTENT, % (C-Mn MICROALLOYED STEELS)

When only one value is given max. content is indicated.

Element	DnV ship rules	DnV fixed offshore structures	BV	DoE (BS 4360)	API e.g. (ASTM A131)	API 2 H tubular joints	USGS
Ti	0.05	0.08			0.015		
Mn	0,9-1,6	1,6	1,6	1,6	1,6	0,9-1,35	Only
Si	0,1-0,5	0,5	0,5	0,5	0,5	0,15-0,30	as
S	.04	0,04/0,05	0,04/0,05	0,025/0,04/0,05	0,05	.035	restricted
P	.04	0,03/0,05	0,04/0,05	0,025/0,04/0,05	0,05	-	by
Nb	.05	0,05	0,04/0,05	.003/0,10/0,15	0,05	-	listed
Cu	.35	0,35	0,35	-	0,35	-	ASTM
Cr	.20	0,20	0,20	-	0,25	-	and
Mo	.08	0,08	0,08	-	0,08	-	API
Ni	.40	0,40	0,40	-	0,40	-	grades
V	.10	0,10	0,05-0,10	0,003/0,10	0,10		
Al	0,08	0,08	0,06				
N		0,009 (0,015)			0,015		

4. TENSILE PROPERTIES

4.1 Strength classes

Both regulations and rules divide the steels in different strength classes depending on their minimum specified yield strength. Both designations and ranges varies and overlap, see Table 6.

Higher strength materials may require special evaluation and approval procedures. The main reasons are that the higher strength materials may be more difficult to weld and form, and may also be more prone to corrosion fatigue and stress corrosion cracking.

TABLE 6 TYPICAL REQUIREMENTS ON TENSILE PROPERTIES - ROLLED PRODUCTS

	Tensile/yield strength MPa	Elongation %	Reduct. of area % (thickness direction) 1)
NPD	320-510/190-350 (NS 12101) no clear limits	min 18-23	min 20
DoE	/210-390 no clear limits	min 18-23	min 20
USGS	400-1.15 y.s/200-690		may be required unless special welding procedures are used ultrasonic testing applied
API RP 2A	380-690/205-415	min 19-26	for API - 2H steel
Ger. Lloyd	400-620/235-355		min 25
Bureau Veritas	390-620/235-255	min 20-22	grade Z15 15% grade Z25 25% grade Z35 35%
DnV	min spec yield strength normally less than 390 yield/tensile < 0,85	min 21-22 (round bars) min 14-21 (flat bars)	min 20
ABS	410-630/240-360	min 19-24	may be required (Practice: 20-25%)
Lloyds Register	Reference only to ship grades steel		Not indicated (required in practice)

Note 1): The RAZ-values only apply when the steel is required to have guaranteed through thickness ductility.

4.2 Strength levels

Most of the structural steels used have minimum yield strength specified in the range 240 to 360 MPa while the tensile strength is specified in the range 430 to 690 MPa. Steels of higher yield and ultimate strength levels are also used, particularly for jack-ups, tension legs and piles.

For thicker sections the yield strength is incrementally reduced, and may drop to 300 MPa for a steel normally specified to have 360 MPa in moderate thicknesses.

Another restriction is the yield strength (R_{EH}) to tensile strength (R_M) ratio for which a limit of

$$\frac{R_{EH}}{R_M} < 0.85$$

has been stipulated (DnV, fixed structures). The objective is to ensure that the base material will exhibit macro yielding before fracture.

4.3 Ductility (x, y direction)

The regulations are rather specific on minimum elongation specified in the range from 18 - 26% depending on strength levels and type of tensile specimens. The low value corresponds to elongation for extra high strength steels.

Ductility requirements rarely result in material rejection. For extra high strength steels elongation may however be more difficult to meet.

4.4 Ductility (Z-direction)

Exploration and production activities in the North Sea have required larger and more complex platforms. Material dimensions have increased and resulted in heavier, more rigid welds. The materials therefore have to sustain greater through thickness loads due to residual welding stresses and service stresses, and therefore need to have good through thickness ductility.

In order to prevent materials with planes of weakness, both regulations and rules point out the needs for steels with guaranteed through thickness ductility (RAZ). (This is normally measured as the reduction of area on a conventional tensile test specimen.)

The specified RAZ-values normally vary from 20 to 35% (see Table 6). The difference has to be seen in conjunction with the diameter of the test specimen. The lower value is typical for regulations and rules while project specifications tend to require what is easily obtainable (35%) with modern steel making technology.

While through thickness property is a mandatory requirement for critical Z-direction loaded members in fixed structures, it is sometimes only suggested in rules for mobile units.

Most of Veritas experience is based on a specification value of average RAZ to be 20%. This has proved to be fully adequate to prevent lamellar tearing in very restrained and thick T, Y, K and X joints.

The repair and delay costs of lamellar tearing problems are much greater than the extra steel costs. Designers and operators therefore now specify Z-type steels to a much greater extent than a few years ago. The high RAZ-value and low S-levels specified (< 0.009) may easily be met with modern steel making using Ca-treatments techniques. In fact the process route may give Z-quality steel even without being a delivery condition.

Z-steel was first introduced for plates. A growing attitude is to specify the properties for the steel without consideration to the type of product. RAZ-values are therefore now also specified for rolled sections, beams and shapes.

When lamellar tearing occurs today, it is typically encountered in construction using conventionally processed beams and sections.

The trend to cleaner steel has incurred a higher risk of H-flakes in the steel with very low S. Unless the steel has been vacuum treated, hydrogen effusion treatment may have to be carried out after casting.

5. NOTCH TOUGHNESS

5.1 Design basis

Design against brittle fracture has a great influence on material selection and its application. This is a design condition to which governmental bodies and classification societies have given great attention. The reasons are obvious -an offshore structure may be exposed to severe loading resulting in local yielding also at rather low temperatures. The design philosophy of different sources can vary, and therefore actual requirements on for example Charpy V properties must be seen in context with this.

Mobile units have traditionally been treated like ships for which the design concept against brittle fracture may include or even rely on high toughness materials to give crack/fracture arrest, e.g. application of E-grade steels.

For fixed structures, at least for those in the North Sea, most concepts do not take into account crack arrest. It is then believed that the driving energy introduced in the structure by extreme wave loads would be much higher than the materials ability to absorb even if the steel was very tough. Another important consideration is that temporary strengthening or repair work may be very difficult. Therefore the design against brittle fracture in fixed structures aims at preventing initiation of an unstable fracture.

5.2 Test temperatures vs. design temperature (Charpy V-requirements)

When fracture toughness tests are required, the test temperature is normally lower than or equal to the design temperature.

There are two principal methods of specifying impact requirements:

a) When the test temperature = design temperature or service temperature, the Charpy V energy requirement is set at sufficiently high values, i.e. specifying high upper shelf energy for arrest performance.

b) For a given Charpy energy requirement, the test temperature is lowered, often as a function of material thickness to ensure a low transition temperature.

Both methods are used for offshore structures but there seems to be a tendency to prefer the latter approach by most societies.

DoE

The current approach taken by Dept. of Energy, U.K. (DoE) is shown in Fig. 6 a. The test temperature is decreased as a continuous function of material thickness. Minimum requirements for notch toughness are 27 Joule at 280 MPa yield strength level and 34 Joule at 355 MPa level. (There are however proposals for revised requirements which would mean lower testing temperatures and higher energy values being adopted.)

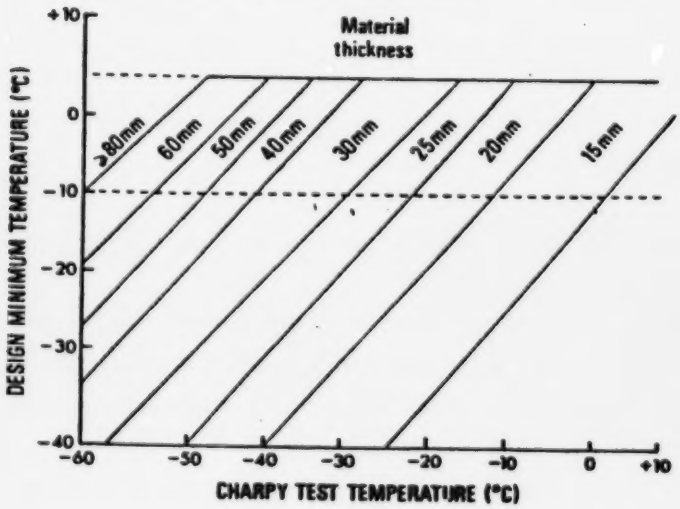
Minima values for notch toughness

References (see footnote)	Strength level Maximum value of minimum specified			Charpy V notch test requirements (before stress relieving)		
					Temperature °C	
Steel	Yield stress N/mm²	Tensile strength N/mm²	Thickness mm	Energy joules	Not to be stress relieved	To be stress relieved
1 Mild steels for	280	430	≤25	27	−5	
2 structures (as rolled;	280	430	>25	27	−20	−10
3 controlled rolled;	280	430	≤20	27	−20	
4 normalised)	280	430	>20	27	−40	−30
5 Higher tensile steels	355	500	≤25	34	−5	
6 for structures	355	500	>25	34	−20	−10
7 (controlled rolled;	355	500	≤20	34	−20	
8 normalised; Q & T)	355	500	>20	34	−40	−30

Used for fixed structures

Figure 6.1

Minima values for notch toughness (as-welded condition)



Optional for mobile units, alternatively the Rules of the C.A. may apply.

Fig. 6 a DoE's criteria to impact toughness for structural steel

NPD

In the approach adopted by Norwegian Petroleum Directorate (NPD) shown in Fig. 6 b, the minimum Charpy energy requirement is a continuous function of yield strength whereas the thickness effect is accounted for by discrete step changes. The NPD regulations stipulate the CV-energy requirement as function of min. specified yield strength, while the testing temperature is related to the categoty of the member and its thickness (see fig. 6 B).

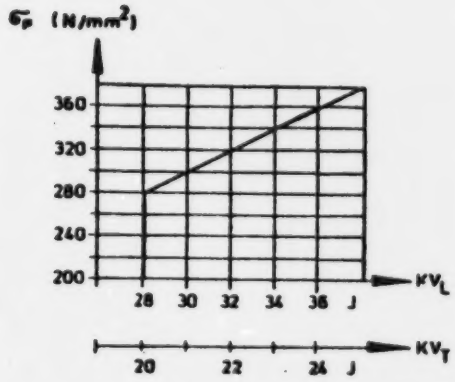


Table 1: Testing temperature T (°C)

Material thickness	Steel for members essential to the safety of the structure		Steel for other members
	Subject to high stress in the thickness(1) direction(10	Subject to stresses mainly in the plate plane	
t ≤ 12	T = T_D	T = T_D	
12 < t ≤ 25	T = T_D - 20	T = T_D	
25 < t ≤ 50	T = T_D - 40	T = T_D - 20	T = T_D
t > 50	T = T_D - 40	T = T_D - 40	T = T_D - 20

KV_L – Energy absorption in longitudinal direction
KV_T – energy absorption in transverse direction
σ_p – yield stress
T_D – minimum design temperature

NPD guidance (Fixed Structures).
Fig. 6 b

DnV

DnV has issued different rules for mobile units and fixed structures, and the notch toughness requirements vary somewhat depending on the minimum design temperature (T_D). The "mobile" rules refers to ship grade requirement and give thickness and application restrictions for different grades. The "fixed" rules (worked out to cover permanent operation at same location) give energy requirements as a function of min. specified yield strength (up to 390 MPa) while testing temperature as a step function of minimum design temperature, member classification and thickness as indicated in Fig. 6 d.

Although not stated in the "fixed" rules, the impact requirements have not been intended to cover design temperatures (as defined by DnV) significantly lower than -20oC.

General requirements.

Design temp.	Type of steel	Grade of steel					
		Thickness max. mm					
		12,5	20.5	25,5	30	35	Unlim-ited
Down to 0° C	NS	A	A	A	B	D	E
	HS	A	A	A	D	D	E
Down to −5° C	NS	A	A	B	D	E	E
	HS	A	A	D	D	E	E
Down to −15° C	NS	A[1])	B	D	E	E	E
	HS	A[1])	D	D	E	E	E
Lower than −15° C	To be specially considered						

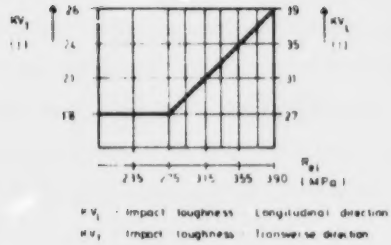
NS = normal strength steel
HS = high strength steel
1) Rimmed steel not allowed

Special requirements.

Design temp.	Type of steel	Grade of steel		
		Thickness max. mm		
		12,5	20,5	Unlim-ited
Down to −5° C	NS.	B	D	E
	HS	D	D	E
Down to −15° C	NS	D	E	E
	HS	D	E	E
Lower than −15° C	To be specially considered			

NS = normal strength steel
HS = high strength steel

Fig. 6 c Impact requirements according to DnV Rules for mobile units



Specimen cross section (mm²)	Fraction for minimum energy
10x10	1
10x7.5	5/6
10x5	2/3

Impact testing temperature

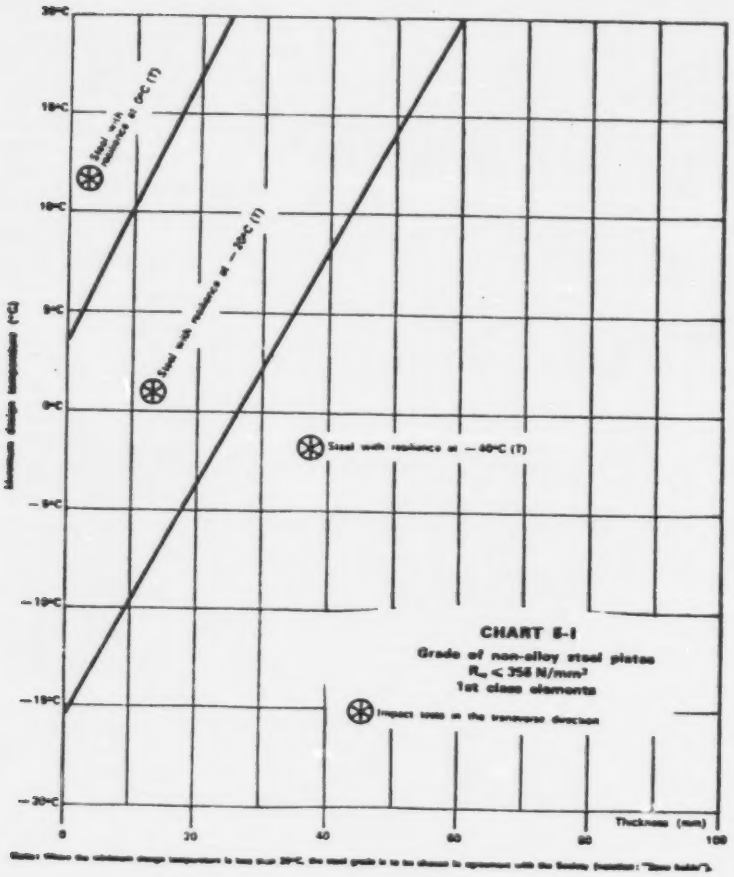
Material thickness, t mm	Special structural steel	Primary structural steel	Secondary structural steel
t≤12.5	$T = T_D$	$T = T_D$	
12.5<t≤25.5	$T = T_D - 20$	$T = T_D$	
25.5<t≤50	$T = T_D - 40$	$T = T_D - 20$	$T = T_D$
t>50	$T = T_D - 40$	$T = T_D - 40$	$T = T_D - 20$

T = Impact testing temperature (°C)
T_D = Design temperature (°C)

Fig. 6 d Impact requirements according to DnV Rules for fixed structures

BV

The Bureau Veritas approach is somewhat more complicated and is described in Fig. 6 e, which gives the impact requirements for the "1st class elements". Similar graphs have been included in BV rules for 2nd and 3rd class elements. BV's energy values are asigned to two discrete yield strength levels are assigned and the thickness effect is accounted for by step changes in the impact testing temperature. The philosophy is similar to that adopted by DnV for classification of mobile offshore units.



STEEL GRADES DEFINED BY THEIR MINIMUM ENERGY AT IMPACT TEST

Steel grade	Test temperature	R_{eH} < 275 N/mm²			275 < R_{eH} < 355 N/mm²		
		1st Class	2nd Class	3rd Class	1st Class	2nd Class	3rd Class
Grade at + 20°C	+ 20°C		27 (L)	27 (L)		34 (L)	34 (L)
Grade at 0°C	0°C	20 (T)	27 (L)	27 (L)	24 (T)	34 (L)	34 (L)
Grade at − 20°C	− 20°C	20 (T)	27 (L)	27 (L)	24 (T)	34 (L)	34 (L)
Grade at − 40°C	− 40°C	20 (T)	27 (L)		24 (T)	34 (L)	

R_{eH} : minimum guaranteed yield stress

L : fracture energy in the longitudinal rolling direction, in Joules

T : fracture energy in the transverse rolling direction, in Joules.

Fig. 6 e Impact testing requirements according to BV Rules
(Note: The BV Rules contain additional charts for other steel types.)

LR

Lloyds Register divides the impact requirements into parts below and above water. In all submerged regions with high stress where good notch ductility is essential, LR-Grade E and EH steels (i.e. T = -30 and -40°C) are to be used for all thicknesses (i.e. LR primary member). In other below water parts, the following applications are recommended:

Thickness (mm)	20.5	25.5	50	LR secondary/ below water joints
Grades:	A	B	D	
	AH	AH	DH	

Above water exposed parts are to be tested in accordance with the following conditions:

MINIMUM SERVICE TEMPERATURE DOWN TO	GRADES OF STEEL	
	Primary Structure	Secondary Structure
0°C (32°F	As for underwater structures (*See* 202)	
−5°C (23°F)	D	D
−10°C (14°F)	E	D
−20°C (−4°F)	E	E
−30°C (−22°F)	(*See* Note 1)	(*See* Note 2)
below −30°C (−22°F)	(*See* Note 1)	(*See* Note 3)

NOTES

1. The steel is to have a minimum average Charpy V-notch impact test energy of 6,2 kg m 45 ft lb at the temperature concerned (*see also* Note 4).
2. For thicknesses not exceeding 15 mm (0·6 in), Grade E steel may be used. For thicknesses over 15 mm (0·6 in) the steel is to have a minimum average Charpy V-notch impact test energy of 4,8 kg m (35 ft lb) at the temperature concerned (*see also* Note 4).
3. The steel is to have a minimum average Charpy V-notch impact test energy of 4,8 kg m (35 ft lb) at the temperature concerned (*see also* Note 4).
4. The minimum average energy is to be for three standard Charpy V-notch test specimens taken from each "piece" (*see* Chapter P of the *Rules for Steel Ships*). For subsidiary Charpy V-notch test specimens, minimum average energy values are to comply with values given in Table P 2.2 of the *Rules for Steel Ships* at the temperature concerned.

Fig. 6 f Lloyds' recommendations to notch toughness properties.

ABS

ABS' principles for derivation of notch toughness requirements for ordinary and higher strength ship grades are similar to those given in other rules for mobile units. The effect of thickness is accounted for by means of thickness restrictions in different applications and steel grades as shown in Fig. 6 g.

Material Selection Guidelines (ABS)

Numbers in table are maximum thicknesses in mm (in.)
Blank areas indicate no application

Service Temperature	Secondary Applications				Primary Applications				Special Applications			
°C	0	-10	-20	-30	0	-10	-20	-30	0	-10	-20	-30
°F	(32)	(14)	(-4)	(-22)	(32)	(14)	(-4)	(-22)	(32)	(14)	(-4)	(-22)
Grade A	51 (2.00)	19 (0.75)	12.5 (0.50)		19 (0.75)	12.5 (0.50)						
B	51 (2.00)	25.5 (1.00)	19 (0.75)	12.5 (0.50)	25.5 (1.00)	19 (0.75)	12.5 (0.50)		16 (0.63)			
D, DN	51 (2.00)	35 (1.375)	35 (1.375)	22.5 (0.89)	35 (1.375)	35 (1.375)	22.5 (0.89)	12.5 (0.50)	22.5 (0.89)	16 (0.63)		
DN	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	27.5 (1.08)	22.5 (0.89)	16 (1.08)	
E, F	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)
AH	51 (2.00)	25.5 (1.00)	19 (0.75)	12.5 (0.50)	19 (0.75)	19 (0.75)	12.5 (0.50)		19 (0.75)			
DH	51 (2.00)	51 (2.00)	51 (2.00)	19 (0.75)	51 (2.00)	51 (2.00)	19 (0.75)	12.5 (0.50)	19 (0.75)	16 (0.63)		
DHN	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	27.5 (1.08)	22.5 (0.89)	16 (0.63)	
EH	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)

Fig. 6g ABS recommendations and requirements

For other type of steel (than ship grade steel) and extra high strength grades the Charpy energy (CVL) is also 34 Joule. The testing temperature is reduced in steps, which also depends on the minimum service temperature. For example special steel expected to encounter a daily temperature of -10°C is tested at -50°C and primary at -40°C. (See Fig. 6 h.)

When the minimum temperature is reduced to -20°C, the testing temperature is not changed. ABS does not stipulate any thickness restrictions for these steels.

Fig. 6 h: ABS' impact requirements for other than ship grade steels.

Yield strength	CVL-energy	Testing temperature			Nil Ductility Temp.
R_{EH} 300	27 J	Special: T_S -30 Primary: T_S -10 Secondary: T_S			T_S -35 (°C)
R_{EH} 400	34 J				T_S -15
R_{EH} = 415 to 690		T_S	Special	Primary	T_S -5
		0	-40	-30	
		-10	-50	-40	
		-20	-50	-40	
		-30	-60	-50	

API

API RP-2A recommendations to notch toughness are related to steel grouping (i.e. API's strength classes) and the steel classes (application).

Steel Class	Classification criteria - plates 1)	Toughness requirements
C	Service temperature above 0°C moderate thicknesses minor cold deformation simple joints	None
B	Where thickness, cold work, restraint, stress concentration, impact loading, lack of redundancy indicate need for improved notch toughness 2)	Group I: 20 J CVL Group II: 34 J CVT at the lowest anticipated service temp.
A	Subfreezing temperatures and critical application involve adverse combinations where crack arrest performance of large flaws is required.	34 Joule at 20 to 30°C below lowest anticipated service temp.

Notes 1) For cold worked tubulars ($D/t < 30$) one higher class of steel should be considered to sustain toughness degradation or tests run at a reduced temperature.
$D/t > 30$: $T = T_S - 20°C$ on plates
$D/t = 20\text{-}30$: $T = T_S - 30°C$ on plate
$D/t < 20$: $T = T_S - 10$ on tubular

2) For above water tubular joints exposed to low temperature or impact loads from boats class A steel should be considered. Alternatively the CV-test may be replaced by a drop weight testing and meet no break criteria at the same temperature.

U.S.G.S.

U.S. Geological Survey's guidance on toughness characteristics follows the principles given by ABS for other steels than their ship grades. While ABS specify average CVL energy of 27 Joules for all ordinary strength steels, i.e. $R_{EL} < 280$, U.S.G.S. has relaxed this to 20 Joules for $t < 38$ mm. All U.S.G.S. requirements refer to testing of plates.

5.3 Comparison of notch toughness requirements

Direct comparison of the notch toughness requirements given in the regulations and rules is not simple because definition of design/reference temperature (see 1.5) impact energy, direction of testing and condition (plate versus tubular) may vary.

A comparison of testing temperature is attempted on the following basis:

1) Minimum design temperature as defined by DnV/NPD taken to be 10°C higher than the minimum design temperature defined as lowest daily average temperature
2) Energy conversion based on 1.5°C/J as recognized per BS 5500 "Unfired Pressure Vessel".
3) Higher strength steel $R_{EH} = 360$ MPa
4) Thickness t = 30 and 60 mm.
5) Testing according to ABS, DnV (fixed), LR, GL, DoE, NPD and U.S.G.S.

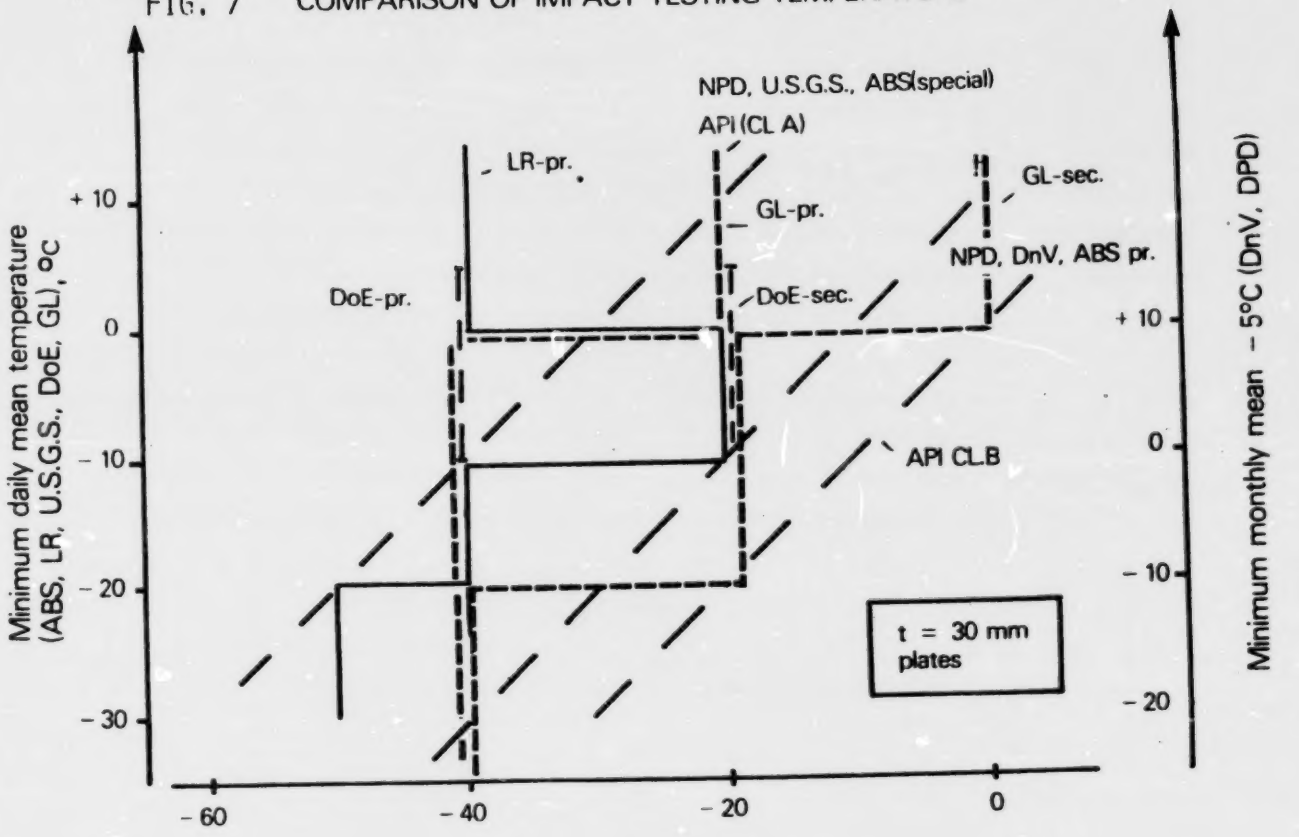
The results are shown on figure 7 a and 7 b. They indicate that NPD, U.S.G.S, DnV, ABS and API have similar requirements for critical members for both thicknesses, while ABS/API/U.S.G.S. are less stringent for 60 mm thick primary members.

A comparison of CV energy requirements as a function of yield strength are incicated in Fig. 8.

Up to about 270 MPa yield strength the requirements are very similar, except for API which requires a lower value, 20 Joule.

In the range 270 - 340 MPa yield strength the NPD and DnV energy requirements are slightly less than those of BV and API. However, at higher yield strength, the DnV and NPD rules tends to be more strict.

FIG. 7 COMPARISON OF IMPACT TESTING TEMPERATURE



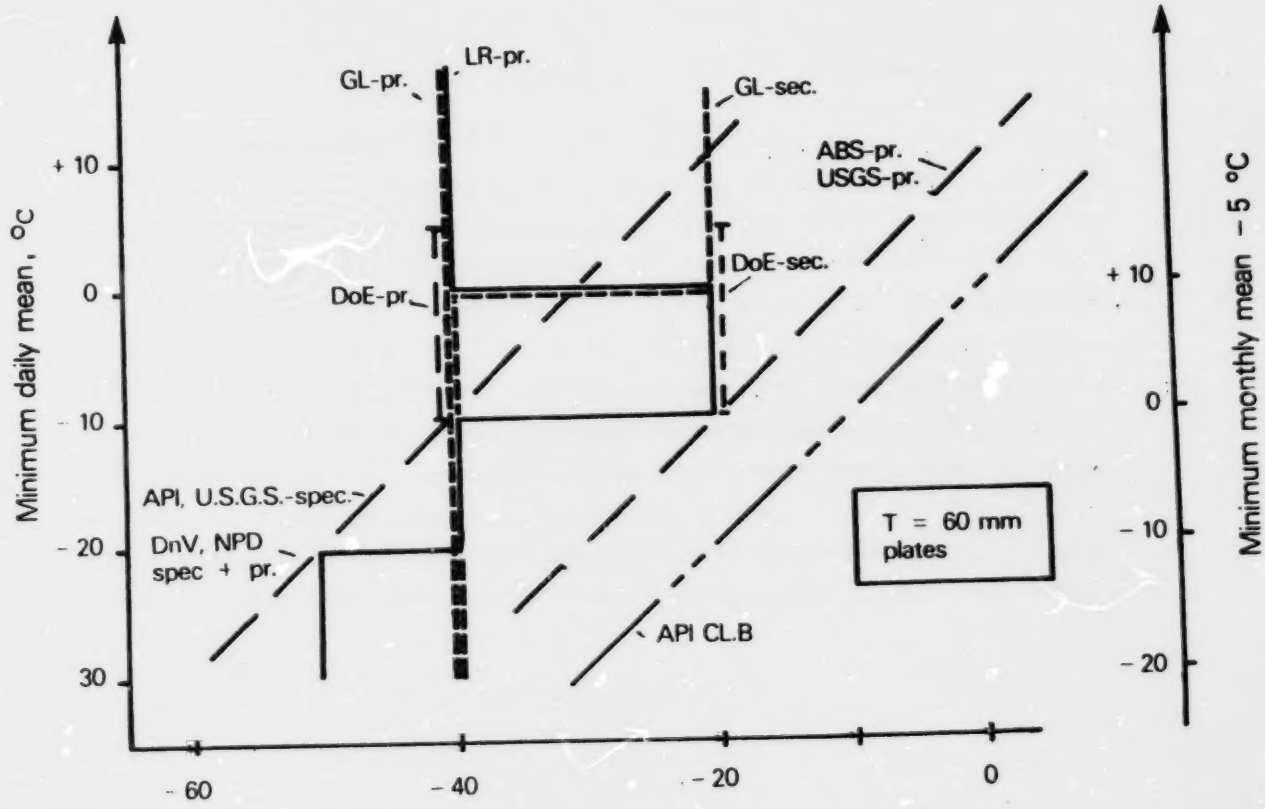
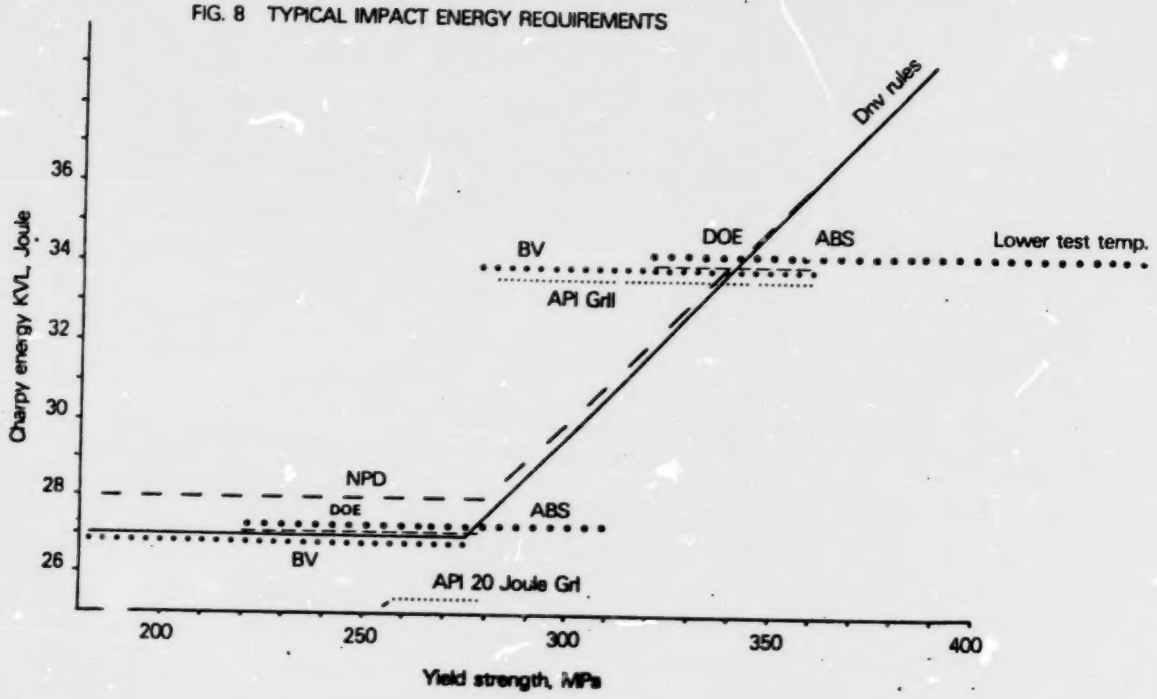


FIG. 8 TYPICAL IMPACT ENERGY REQUIREMENTS



5.4 Extrapolation of CV-requirements

The described CV-requirements are principally of empirical nature, and have been extrapolated largely from the experience with catastrophic failure in ships during and after second world war. These failures did happen in steels of moderate strength and thicknesses, and at service temperature not too far from 0°C. Accordingly one has to be careful if extrapolating such empirical based requirements to significantly different strain levels, thicknesses and temperatures. There is still no concensus whether one may use the present relations between impact testing temperatures and minimum design or service temperatures, where the latter is much lower than -20°C or -30°C respectively, or thicknesses far exceeding 50 mm. In fact most Classification Societies require that the material selection are to be specially agreed upon for long or permanent service in arctic region. The U.S.G.S. regulations do not yet cover such areas as Alaska.

The reported instances of brittle fractures in offshore platforms are few. They have however occurred also in North Sea structures, then either due to bad workmanship, material mixing, incorrect or lacking heat treatment or design error in material selection. To our knowledge brittle fractures have only occurred in one instance in structural steel meeting the specified toughness level. This happened during platform construction, while a small hydrogen induced crack triggered a local brittle fracture in a very severely restrained stiffener.

North Sea experience does not indicate that present regulations or rules need to be revised significantly in terms of CV-requirements for steel structures operating in this area. There has, however, been made proposals to DoE that their requirements for toughness of welds should be made slightly more stringent.

6. SOUNDNESS OF STEEL

The NPD regulations give only indirect requirements for soundness by the reference to national standards. It is characteristic of steel standards that the required soundness is to be "suitable" for its intended use and made workmanlike. DoE and U.S.G.S. do however point out that laminations represent weak planes, and appropriate checks may be necessary.

Also the rules of the Classificiation Society are not always specific about soundness and laminations although their approval scheme of steel mills includes requirements for such evaluation.

Veritas Rules for fixed structures require special and primary steel to be ultrasonically examined for laminations according to recognized standards.

Frequently specified standards for ultrasonic testing of plates are:

- S.E.L. 072-77 Class 3 or 2
- ASTM A 435 and 578 - Level I
- BS DD-21/Grade A 1

Even if these standards are only covering plates, they are also referred to for examination of heavy sections.

7. FABRICATION REQUIREMENTS

7.1 General

Fabrication specifications will normally contain requirements to:

- o Construction standard
- o Welding processes
- o Selection, handling and storage of welding consumables
- o Welding procedure specification
- o Qualification of welding procedures
- o Qualification of welding personnel
- o Forming methods and limits
- o Joint configurations and weld details
- o Preparation and performance of welding
- o Preheating
- o Heat treatment after forming and welding
- o Repair welding
- o Dimensional tolerances, global and local
- o Inspection and testing of weldments
- o Production testing of weldments

The principal scope of this report is to review the properties of materials and weldments. In the following only those of the above mentioned items which directly control the properties of the structure are considered. Other aspects like non-destructive testing, dimensional tolerances etc. are not covered although they may have significant influence on the soundness and integrity of a structure.

7.2 Construction standard (fabrication and welding)

The designer will normally specify the standard or codes to be followed during construction. For mobile units these will always include the rules of the appointed classification society. It is common to reference ship rules or recognized standards also for fixed platforms. The regulatory guidelines may give options to apply different standards.

Table 7: Summary of principal construction standards for fabrication

NPD	Norwegian standard NS 3472 "Design of steel structures"
DoE	Mobile units: Recognized codes + rules of the classification society appointed as Certifying Authority
	Fixed structures: API RP 2A/AWS D1.1, BS 153, BS 5135 subject to any additional requirements needed to meet the more onerous conditions applying to structures in UK waters.
U.S.G.S.	AWS D.1.1 "Structural welding code" or other appropriate welding codes.
DnV	Fixed structures: Recognized standard subject to additional rule requirements
	Mobile units: Ship rules, accepted practice.
Lloyds Register	Rules for steel ships
Bureau Veritas	Rules and Regulations "Characteristics and Inspection of materials. (Special publication issued 1980)
ABS	Rules for Mobile Offshore Drilling Units (however very similar to AWS D.1.1)
Germanischer Lloyds	"Rules for offshore units" giving general supplementary requirements to GL "Rules for welding (hull)".
Nippon Kaiji Kyokai	Rules for mobile offshore units/Part B and P of the rules for the survey and construction of steel ships

7.3 Welding processes

By reference to accepted practice and recognized construction standards all welding processes could be used. In practice only fusion welding methods are applied, and then the manual metal arc, gas metal arc, flux cored arc or submerged arc processes are specified. Other high heat input processes, e.g. electrogas and electroslag, are not common in fabrication of offshore platforms, and would normally be excluded due to the difficulty of obtaining adequate notch toughness in special and primary members. Where electroslag welding has been selected, double re-normalizing has been part of the fabrication sequence.

DnV Rules, U.S.G.S. guidelines/appendixes, ABS and AWS D.1.1 also call for special qualification testing for high heat processes. There seems (in Europe) to be a general agreement derived from fracture mechanics testing of the heat affected zone, that heat inputs higher than 4 kJ/mm will reduce the HAZ-toughness of structural steel (even if meeting the NPD and DoE requirements for the plates) so much that special testing and evaluation is justified. This heat input appears to emerge as a "threshold limit", for the tolerable heat input when the more stringent toughness limits for fixed structures shall be fulfilled. This also seems to be the case for multiwire submerged arc welding. Thus the triple-arc technique is not common even for welding tubulars. Contrary to this experience is the U.S.G.S. requirement to only ask for HAZ-testing for heat inputs higher than 80 kJ/mm.

Flux cored arc welding (FCAW) has attractive features due to high producivity particularly in positional welding as often occurring in welding of tubular node joints. However, it has taken a long time to get the self shielded FCAW recognized, and there are still many having reservations about the consistency of properties and the high dependance of skilled operators.

7.4 Welding consumables

Selection of welding consumables has become very important for the fabricators because either regulatory guidelines, Classification Societies' rules or at least operators' specifications require more stringent characteristics with respect to diffusible hydrogen level and weld metal toughness than necessarily guaranteed through the normal approval schemes for welding consumables. The programs are based on testing of an all weld metal sample, while the real interest is welds made under practical fabrication conditions.

Special property restriction and selection criteria are summarized in Table 8.

Table 8 Summary of special property restrictions and selection criteria

NPD	1) Low hydrogen consumables for welding steels with R_{EH}>300 MPa 2) Diffusible [H] < 5 ml/100 g deposit for "special" members Diffusible [H] < 10 ml/100 g deposit for other members 3) Selection based on fracture mechanics for welds where high local strain may occur.
DoE	1) Consumables to be approved by the C.A. 2) Low hydrogen consumables for welding steels for R_{EH} > 280 MPa 3) Selection based on defect tolerances estimated from fracture mechanics tests or other suitable tests.
U.S.G.S.	Only as per AWS D.1.1 and the general conditions of meeting the given strength, ductility and toughness properties "compatible" with the base metal.
DnV	Fixed Rules: 1) Low hydrogen consumables if CE > 0.41 2) Extra low hydrogen electrodes for welding of "special" steel and repair. 3) Type approved product 4) Selection based on fracture mechanics data for application to thick welds (t > 50 mm) Mobile Rules: 1) Type approved product 2) Applications depending on steel grades 3) Notch toughness as min. required for base steel
LR	Consumables are to be approved by LR.
ABS	Low hydrogen consumables recommend for all higher strength grades, and lower strength steel subject to high restraints.
B.V.	1) Approved filler products list published 2) Inspection and approval procedures listed in Steel Ship Rules 3) For manual welding low hydrogen basic electrodes
GL	1) Approved in accordance with GL "Rules for Welding (Hull)" 2) Basic electrodes for welding thick steels, castings or higher strength steels being part of the primary structure.
API	1) Comply with appropriate AWS specifications 2) If AWS approval does not require impact testing, then testing to prove 27 J/-18°C in weld metal for application in nodes and higher strength steels
NKK	No special guidelines given in their "Rules for Mobile Offshore Units", i.e. ship practice apply.

While it for the construction of mobile units is normal practice to only require approval of the consumables, the approach for fixed structures is to take this approval as a guidance for the moisture/hydrogen characteristics of the consumables. The final acceptance of a particular consumable is then based on the rules from procedure qualification testing.

The control of storage and handling of consumables has received close attention in connection with the construction of fixed platforms. In many cases the general recommendations of the consumable manufacturer have been found insufficient. Moisture pick-up tests have clearly shown that low hydrogen consumables may behave very adversely when exposed to relatively low humidity. Thus in order to ascertain that the assumed LH-characteristic is maintained until use, stringent storage and handling routines have been imposed. The reduction in repair rates and costs have also clearly justified these routines. The new generation of "moisture resistant" electrodes is a direct response to such requirements. Improved packages/sealings is also a development in this direction.

A typical project specification for storage and handling procedure for low hydrogen consumables (of class AWS 70 and 80-series) would be:

Main stock	T > 20°C (hermetically sealed packages)
Storage oven	T > 100 - 150°C at least one hour
Heated oven	T > 70 - 80°C electrodes to be used within 2 - 4 hours after withdrawal from the oven
Drying oven or baking furnace	250 - 300°C / 1 - 2 hours 350 - 450°C / 1 hour

Most attention has been given to coated electrodes. Moisture pick-up is however not restricted to only these consumables, but also fluxes may be very hygroscopic. The increased use of alloyed, highly basic fluxes of the agglomorated type has been accompanied by a number of incidences of transverse weld metal cracking, particularly in thicker materials. Consumable manufacturers are thus much more alert to this problem than before, and some may now give very detailed advice on storage, handling and recycling of their products.

The trend to increasing use of extra high strength steels will probably result in even more emphasis in this area.

7.5 Welding procedure specification

It is required by the NPD, DoE and U.S.G.S.'s regulations, as well as DnV, LR, ABS, BV, GL, API and the operators, that the fabricator works out detailed welding procedure specifications. The required level of detailing may vary, but generally all variables considered essential and their acceptable fluctuation ranges are given.

Such specifications are to be established for both production and repair welding.

The specifications are to be submitted for review or approval. Typical elements of the welding procedure specification are:

- applicable standard/code
- selected basic material
- joint design and material thickness
- welding position
- welding process
- welding characteristics necessary for determination of heat input
- welding consumable brand(s) and classification(s)
- pre- and postweld heat treatment
- qualification range (dimension, joint configurations)

7.6 Practice for qualification of welding procedures

One significant difference between construction of mobile units and fixed platforms is in the practice of procedure qualification testing.

For mobile units the approach has generally been to give an initial approval of the fabricator based on his overall competence and relevant experience, with special qualification testing limited to new types of welding methods and equipment (for the yard) and specially demanding materials or important design details.

Table 9 Requirements for welding procedure qualification testing for mobile units.

DnV	Procedure tests required for new materials, welding processes or special complicated connections.
LR	Procedures to be discussed. Otherwise only reference to Rules for steel ships.
ABS	Procedures to be established before construction. (Prequalified procedures without testing accepted as per AWS D.1.1) Special welding techniques require special considerations.
BV	Approval of welding procedure to be given before the beginning of fabrication
GL	Test welds are to be made under normal operating conditions

For fabrication of fixed structures the attitude is rather the opposite and to require a great number of procedure tests for the different principal joint connections and the given qualification ranges. Many operators also insist on new procedure tests particularly for their structure and materials. However other operators allow the transfer of recently qualified procedures which are found relevant. Also the regulatory guidelines may be strict about the performance of welding procedure qualification.

Table 10 Requirements for welding procedure qualification testing for fixed units

NPD	Qualification testing required. Qualified thickness range 0.75 - 1.5 t for $t < 35$ mm; +25% for grt. $t > 35$ mm
DoE	To be verified through sample weld preparation and testing. Specially required for Y and K-type joints. Qualified range + 0.5 test thickness. Reference to BS 4870.
U.S.G.S.	All welding procedures shall be tested and certified. Previously tested and certified procedures shall be considered prequalified.
DnV (fixed)	Qualification testing required for special and primary weld joints. Also for secondary of $t > 25$ mm. Detailed guidance on essential variables and tolerable changes, i.e. dimensions, joints, materials welding parameters, consumables, preheat, stress relief.
API RP 2A	To be qualified in accordance with AWS D.1.1 with supplementary conditions about weld metal toughness, and initial approval testing for gas metal arc welding
AWS D.1.1	Have options for prequalified welding procedure specifications excempting any testing except for high heat input processes. Sample testing of special node joints may be required for evaluation of soundness.

7.7 Principal criteria for qualification of welding procedures

Mobil units

Type and number of tests as well as the applicable requirements are not always clearly expressed in all rules for mobile units. Where the same rules would cover both mobile and fixed structures, e.g. Bureau Veritas, the test program may be defined in detail. The ABS, LR, GL and DnV Rules (for mobile units) give little guidance beyond the general statement that the base metal properties should be met or that welds are to exhibit comparable or compatible properties. Special qualification programs have however been worked out by the three last societies, and are imposed when found necessary.

Impact testing is normally conducted at the same temperature as specified for type approval of the particular consumable. The Bureau Veritas approach is somewhat different as a +20°C relaxation of testing temperature is allowed for as-welded joints of grade D and E-steels (or similar), but no relaxation where post weld heat treatment is planned.

In special cases the test program will include tests other than the common transverse tensile, bending and Charpy V-tests. This may then be macrosections, hardness tests and fracture mechanics testing. Only B.V. has a general rule requirement for macrosection/hardness tests. The extra tests are otherwise mostly taken as supplementary information in an overall evaluation for welding of special connections or special materials without using the additional, individual results as basis for disqualification.

Fixed structures

The qualification program and criteria may be more rigorous in regulations, rules and project specifications pertaining to construction of fixed structures. Recognized construction standards are supplemented with requirements for impact testing, macrosections, hardness tests, and also fracture mechanics testing for thicker, important members. The test specimens are taken from assemblies which are welded in a realistic manner and have the geometry and sizes sufficiently representative of the member to be welded. Thus separate procedure tests may have to be run for fillet welds and groove welds, butt joints and T-joints as well as Y, K shaped tubular node joints. The AWS D.1.1 option on prequalified welding procedures are generally not allowed by those regulations, rules and project specification pertaining to manned installations.

Tensile and ductility requirements are mostly the same as given in recognized welding standards. However impact testing requirements may vary. NPD/DnV (fixed) requires the same testing temperature and CV-energy for the weld metal and HAZ as for the base metal, while DoE allows a relaxation in testing temperature and energy values for weld metal and HAZ. U.S.G.S. requires toughness properties which are "compatible" or "commensurable" with the base metal properties. Testing of the HAZ is only required by U.S.G.S. for welds made with a process giving a heat input higher than 8 kJ/mm.

While DoE allows a slight differentiation in toughness properties between as-welded and stress relieved joints (see Table 11), NPD and DnV do not. U.S.G.S. does not give guidance.

BV and DnV stipulate hardness testing for procedure qualification. BV and DnV's hardness limits are 350 and 325 HV respectively referring to welds in normal and higher strength steels with R_{EH} < 390 MPa. Hardness testing for procedure qualification is common in project specifications, and has been imposed on North Sea constructions by operators as part of their general company specifications. AWS D.1.1 requires hardness testing for evaluation of heat affected zones in submerged arc welds only (see Table 11).

In project specifications the requirements to Charpy V impact toughness of weld metal and HAZ are normally as specified in governing regulations and rules. For some platforms in the UK sector, operators have specified more stringent requirements than imposed by DoE. (The present DoE criteria are subject to reconsideration in view of the results obtained through the European Offshore Steel Research Program.) Only in very special cases has impact testing of welded joints been carried out at a temperatures lower than -40°C for North Sea structures. This is however the testing temperature stipulated both by NPD and DnV, and also by BV for stress relieved joints or in thicker sections.

In comparing impact toughness and hardness criteria, one has to take into account the details of the testing procedure. Position of notching and sampling location (surface, 1/4 t, mid thickness, root etc.) have significant influence on the toughness. Similarly the selected method, load and location of the indentations will be of great importance for the measured hardness values.

Table 11 summarizes the principal and general criteria for qualification of welding procedure as given by rules, regulations and recognized standards.

Table 11 Principal mechanical property limits for qualification of welding procedures.

ABS (mobile units)	1) Strength and toughness comparable to that of the base material 2) Recognized standards e.g. Rules for building and classing of steel ships or AWS D.1.1.
LR (mobile units)	Standard of "Rules for Steel Ships" apply
GL (offshore installations)	1) In accordance with Shipbuilding Welding Rules or other equivalent rules. 2) Other tests like hardness testing may be required.
BV (offshore platforms)	1) Strength and toughness as for base metal 2) Impact testing temperature relaxed 20°C for as-welded joints in D and E-grade steels; no relaxation if stress relieved 3) 180° bend tests 4) Macrosection 5) Hardness max 350 HV 5 for t > 20 mm and CE > 0.43
DnV (mobile units)	1) Base metal properties are generally to be met 2) Impact testing temperature as for type approval of welding consumables.
NPD (fixed)	1) Strength, ductility and toughness of welded joint to meet base metal requirements. 2) Fracture mechanics testing of weld metal.
DoE	1) Testing as per BS 4870 (or other recognized standard) plus additional fracture toughness testing. 2) CV (weld metal and HAZ) > 27 Joule at base material testing temperature, but need not be lower than -25°C as welded or -20°C stress relieved. 3) Special tests for Y and K joints 4) Fracture mechanics testing for consumable selection.
U.S.G.S. (fixed)	1) Tensile properties as for base metal 2) Notch toughness compatible/commensurable with base metal 3) HAZ impact testing only for high heat input processes. 4) Only initial qualification testing 5) Practice of recognized codes, e.g. AWS D.1.1
DnV (fixed)	1) Tensile and bend testing as per recognized standard 2) Weld metal and HAZ toughness as for base metal 3) Macrosection 4) Hardness testing, max. 325 HV 5/10 for R_{EH} < 390 MPa 5) Fracture mechanics testing of thick welds (> 50 mm) in "special and primary" members.
API RP 2A (fixed)	1) As per AWS D.1.1 2) Written procedures even if prequalified 3) Weld metal toughness > 27 J/-18°C 4) Special attention to welding procedures applicable to above water joints exposed to low temperatures and possible impact loads and where higher strength steel is used.

AWS D.1.1	1) By adherence in all respect to specified groove geometry and weld sizes, workmanship criteria, welding processes and techniques, joint configuration as given in pertinent sections, qualification testing is excempted. 2) Where prequalification does not apply, testing to include weld tensile and bend tests. 3) Impact tests only required for high heat input processes. 4) Qualification testing required only of T, Y, K-connections with included anlge below 30°. Evaluation to be based on sections taken from samples joint. 5) Hardness testing of HAZ on submerged arc welds. Max 225 HV in steels of R_{EH} < 415 MPa and max 280 HV for R_{EH} = 415-485.

Additional to the requirements to mechanical properties it is common practice to require non-destructive testing of the procedure test assembly. This practice is supported in some rules and requirements (DnV-fixed, B.V.), regulations (DoE) and recognized welding standards (AWS D.1.1).

7.8 Forming operations

Forming of plates to tubulars may be done in cold, warm or hot condition. Plastic deformation may influence the mechanical properties of the material, and particularly for weld deposits made with certain types of consumables/processes. Cold forming has an embrittling effect by increasing the yield strength and decreasing the toughness. Warm forming carried out within the recommended temperature range for stress relieving would have little influence while hot forming above the transformation temperature (A_1) may degrade strength, toughness and microstructure to a great extent.

This situation is recognized in some rules, regulations and recommended practice, and is summarized in Table 12. Project specifications may restrict max deformation in the range 3 to 5% subject to special evaluation of properties. This is often found tolerable since original toughness properties may far exceed the specified limits. Post weld heat treatment will in many cases be undertaken due to thick welds on those tubulars where t/OD exceeds the permissible limit.
(t = nominal thickness, OD = outside diameter.)

Table 12 Limitations to forming operations.

NPD	Cold expansion limited to 1% circumferential strain.
DoE	Cold expansion max 0.5% circumferential strain.
U.S.G.S.	If cold forming strains exceed 3%, material and welds shall be examined for toughness degradation. If excessive degradation is indicated, stress relief treatment may be necessary. Alternatively a steel of higher impact class should be used.
DnV (fixed)	1) More than 2% cold deformation to initiate either strain ageing tests to actual deformation, or stress relieving. * 2) Forming above 600°C may require new heat treatment to restore acceptable properties.
BV	1) For cold def. > 1%, renormalizing is generally required of non-alloy and microalloyed steels. 2) For cold def. > recommended limit of steel producer, stress relieving is to be performed. 3) Hot forming subject to special evaluation
API RP 2A	For tubes cold formed > 3%, and not subsequently heat treated, due allowance should be made for possible degradation in notch toughness, e.g. by specifying a higher class of steel or run the impact tests at lower temperature.
Project Specifications	2-5% deformation: Strain ageing tests or stress relief > 5% deformation: Stress relief or renormalizing > 10% deformation: Renormalizing

*Note: Apply to semikilled steels. For fully killed normalized steel, the limit is in practice takes as 3 to 4% for special and primary members.

7.9 Preheating

Preheating is a measure basicly applied to prevent cold cracking in materials with limited weldability, or for restrained and thick joints. It is also intentionally used to reduce the hardness level in welding procedures where hardness control is required. Thus preheating is used much more in welding of fixed structures than for mobile units.

Recommendations to preheating temperatures have been derived through various weldability tests, e.g. CTS, Battelle, implant, cruciform joints, Tekken, Y-groove etc. Project specifications normally require a higher preheating temperature than stipulated by AWS D.1.1, and also higher than proposed in the more stringent BS 5153.

Where preheating is required, it is very often applied until completion of welding. For installation welding outdoors and particularly offshore, a higher preheat in the range 125 to 175°C may be specified independent of thickness and composition. An incentive for this is to reduce the risk of delayed cracking, and allow non-destructive testing as soon as possible without delaying the installation work too much. Normally NDT is to be carried out not earlier than 48 hrs after completion of welding.

Table 13 Requirements to preheating - normal and higher strength steels

DoE	As per BS 5135
NPD	No guidance
U.S.G.S.	As per AWS D.1.1
DnV (mobile)	Required if ambient temperature is below -5°C Special evaluation for grades other than ship steels.
DnV (fixed)	1) Thickness and CE-dependant 2) Always for t > 30 mm and local repairs 3) Temperature given in table (vary between 50 and 175°C)
LR	As per "Rules for steel ship"
GL	1) As per "Rules for welding hulls" 2) Continuous monitoring
API RP 2A	As per AWS D.1.1
AWS D.1.1	1) Material, thickness, process and consumable dependant. 2) Min. temperature vary between 10 and 110°C, only higher for thick sections when using cellulosic electrodes.

7.10 Post weld heat treatment

Post weld heat treatment (previously often designated as stress relieving) is a very effective method to increase the resistance to brittle fracture in welds of normal and higher strength steels. The beneficial effect is obtained through relaxation of weld residual stresses and by tempering of the microstructure.

This method is both an accepted and also mandatory requirement in the pressure vessel industry. When DoE (UK) issued their first "Guidance Notes" on Design and Construction in 1974, the requirement in the former BS 1515 (Unfired Pressure Vessel Code) to pwht welds thicker than 1½" was directly implemented. Operators

with extensive experience from process industry, refineries etc. had also taken the same approach, recognizing that node joints would be subject to arduous stress conditions and significant plastic yielding comparable to the condition at nozzle welds.

Post weld heat treatment may impair the notch toughness of base metal in normal and higher strength steels. Accordingly there is still no consensus about the need for pwht, and particularly among those who advocate the philosophy of crack/fracture arrest. Additionally such heat treatment is expensive, and implies special construction procedures with prefabricated parts being heat treated before assemblying into the structure.

The benefit and justification for requiring pwht has however been clearly established through recent years research utilizing fracture mechanics theory and experiments. The results have already influenced regulations and rules, e.g. DnV changed attitude in 1976 and introduced a pwht requirement to welds of thickness above 50 mm in the 1977 rules. DoE relaxed their thickness limit in 1977 to 50 mm for air, 63.5 mm in seawater. A recent proposal to DoE is to specify a limit of 40 mm for nodes while 50 mm remote from those. Both DoE and DnV allow the thickness limit to be raised based on fracture mechanics.

Material thicknesses in mobile units are generally smaller than used in fixed platforms, and are mostly below 40 mm. Shipbuilding practice does not involve post weld heat treatments. This situation is reflected in rules for mobile units which at most include an option to require pwht in special cases.

Some mobile units may still utilize materials in very thick sections, e.g. the rack part in the leg of jack-ups which may have up to 150 mm cross section. This special part is made of extra high strength QT steels. These steels have obtained their high strength and toughness through carefully controlled heat treatment, and could detoriate if given a normal post weld heat treatment. This is at least the explanation why pwht is excempted even if the same type/group of steels are required to be pwht when used in welded pressure vessels.

Requirements to pwht are summarized in Table 14 a and 14 b.

Table 14 a Procedures for PWHT

Code	Max. furnace temp. at start	Max. heating rate °C/hr	Soaking temp. °C and time	Max. temperature difference	Max. cooling rate °C/hr	Local pwht Heated band (min)	Insulation width
Steel structures							
DnV Rules for fixed offshore structures	300°C	ΔT<30°C at lines or planes of symmetri	550 – 600°C 2 min per mm	30°C	ΔT<30°C at lines or planes of symmetri	6 x t at soaking temp.	Max. 300°C at edge of insulation
Bureau Veritas platform rules	–	Not to cause dangerous stresses or deformations	550 – 620°C 1 hr per 25 mm	–	Not to cause danger-our stresses or deformations	To be agreed upon	
AWS D.1.1 structural welding code	315°C	Above: 315°C max. 220°C/hr per 25 mm	590 – 650°C 1 hr per 25 mm	Heating: Max. 150°C in 4,5 m. Soaking: Max. 83°C	Above 315°C max. 275°C/hr per 25 mm	–	–

Table 14 b Thickness limit for pwht of structural welds.

DoE	1) Simple nodes, chord tubulars and buttwelds in braces	Air: t > 50 mm Seawater: t > 63.5 where thickness of the member decides
	2) Complex nodes	Special consideration
NPD	Assessed on basis of fracture mechanics or type tests. (In practice t > 50 mm)	
U.S.G.S.	Not indicated (as per recognized construction code)	
DnV (fixed)	1) Simple joints: t > 50 mm where nominal thickness of the weld decides.	
	2) Restrained joint of complicated design: Special consideration.	
ABS	Not indicated, but may be specified.	
GL	Determined in relation to admissible stresses.	
LR	Not indicated.	
B.V.	May be required in case of assemblies which require delicate workmanship and play a major part in the structure safety.	
API RP 2A	In general not required for the weldable steels listed by API RP 2A and the range of wall thicknesses normally used in offshore platforms.	
AWS D.1.1	Where required by contract drawings.	

7.11 Impact testing of welded joints in "Arctic" structures

A Charpy V-notch testing temperature of -40 to -50°C of welds in normalized microalloyed steels (R_{EH} < 390) would probably be close to the lowest temperature limit where the energy criteria may be expected to be met consistently. Therefore if an approach similar to that used for North Sea structures were to be imposed on steel structures planned for much lower ambient temperature, it may have considerable implications due to the proportionally lower testing temperature. In case of special structural steel parts thicker than 25 mm, the testing temperature would e.g. be $T = T_D - 40°C$.

However, a testing temperature lower than -50°C seems unrealistic for thick sections of the commonly used C-Mn type steels, even if fine grain treated. More probable design alternatives might be one or more of the following actions:

1) Insulate or artificially heat exposed parts
2) Selection of low yield strength steels to obtain adequate HAZ toughness
3) Selection of low carbon alloyed steels
4) Stress relieve thinner sections according to pressure vessel practice
5) Apply fracture mechanics to thinner weld section for estimation of tolerable defect sizes and for selection of adequate materials, welding consumables and fabrication procedures
6) Reduce the probability for surface defects in "critical" weld connections by grinding of weld profiles
7) Use materials other than steel

8. FRACTURE MECHANICS

8.1 General

Traditionally design against brittle fractures has been taken care of by simple quality control tests of materials and welds, and where the toughness requirements have been correlated with practical experience. The Charpy V-notch requirements have not been quantified in tolerable defect sizes versus stress levels.

In the last decade fracture mechanics has been established as a recognized design tool making it possible to do an overall assessment of stress levels, material properties and tolerable defects. This recognition has been assisted by the extensive use of fracture mechanics for offshore installations, and particularly for platforms in the North Sea and comparable demanding areas, e.g. Bass Strait (Australia).

Deep water platforms are huge structures frequently involving very heavy steel sections in critical parts. The wall thickness in tubular joints and plate structures may be in the range of 50 mm to 150 mm. Steel castings more than 300 mm thick have also been applied. These components are usually highly stressed both by static and dynamic loads. The traditional way of extrapolating the Charpy V requirement into these thickness ranges have by many been considered insufficient, and doubtful due to lack of relevant service data.

Fracture mechanics is now mentioned as a supplementary or alternative method for assessing brittle fractures as well as fatigue crack growth in several regulations, rules and project specifications.

Table 15 References to fracture mechanics in regulations and rules.

NPD	1) Welding consumables shall be selected on the basis of defect tolerances estimated from fracture mechanics. 2) Charpy V-notch criteria shall be based on correlation with a suitable type test (e.g. wide plate test).
DoE	1) and 2) as above 3) Relaxation of thickness limit for pwht may be based on fracture mechanics.
U.S.G.S.	Various tests as e.g. J_{IC}, COD may be used to establish alternative toughness criteria to the specified CV-properties
DnV (fixed)	1) Fracture mechanics is to be used in design for assessing the safety against brittle fracture, and may be used for fatigue calculations. 2) Fracture mechanics testing is to be performed for selection of welding procedures for main welds thicker than 50 mm. 3) Fracture mechanics may be used to raise limit for pwht
B.V.	Special brittle fracture tests, such as COD test, may be performed following agreement between the builder and the society.

8.2 Application of fracture mechanics

Application of fracture mechanics has been used in:

- Derivation acceptable stress levels for various members
- Prediction of fatigue crack growth
- Establish suitable fracture toughness requirement for base material and welded joints
- Selection of structural parts requiring post weld heat treatment
- Calculation of tolerable initial defect sizes at various locations
- Specification of the NDT equipment/procedure's capabilities to detect defects

Fracture mechanics has further been used to establish characteristic fracture toughness data for candidate materials as well as to evaluate the significance of existing defects.

In special cases it has also been used to determine the significance of empirical notch toughness tests not complying with the specified quality control requirements. It is a condition that the properties of the considered materials/welds are representative for the population.

8.3 Fracture mechanics testing

Fracture mechanics testing is normally considered when one or more of the following situations arise:

- The structural member or joint is of significance for the integrity of the structure
- Tension loading
- The minimum temperature is in the range of 5°C or lower
- The thickness exceeds 40 to 50 mm

Some design guidelines have stipulated thickness limits above which post weld heat treatment are mandatory. These thickness limits have to be seen in conjunction with the present design and fabrication practice. In order to raise the thickness limit, fracture mechanics testing has been used as justification. However, this approach has to be used carefully and is often restricted to welded joints having a reference thickness up to appr. 75 mm. Where the minimum temperature is less than -10°C, other thickness limits would be justified due to lack of fracture mechanics data. (By reference thickness is meant the nominal thickness at the weld; for T-joints the thickness of the bevelled member is taken as reference.)

The thickness limit range relevant for the type of steels in common use for fixed structures. If the designer considers steels of higher strength levels, i.e. $R_{EL} > 390$ MPa or allow new fabrication methods, the present practice would also need to be specially considered.

8.4 Fracture mechanics test methods

When fracture mechanics testing is considered necessary, suitable type tests (e.g. wide plate tests) and/or standardized fracture mechanics testing methods are used. The tests are performed with design parameters and at strain rates relevant for the structure.

The crack opening displacement (COD) technique is normally specified since no other method at present lends itself to comparatively simple calculations accounting for residual stresses. Other methods such as J-integral and R-curves are not yet used.

A realistic test is to be carried out. This implies welding a test assembly in the relevant welding position using a welding procedure specification and base material of the actual grade and with maximum thickness to be used in the structures. The testing is carried out at the lowest anticipated service temperature. Both weld metal and heat affected zone are normally tested.

8.5 COD test procedure

The COD testing is carried out according to BS 5762/1979 Crack Opening Displacement (COD) Testing (British Standards Institution) where dimensions of the specimens, procedures for testing and analysis of the experimental data, etc. are given. Two types of specimen are given in the standard namely the "preferred test piece" and the "subsidiary test piece". Both tests are carried out in three point bending. The dimension of the preferred test piece is such that lower bound COD values are determined. If less constraint is to be expected in the structure of interest, this may be modelled by the subsidiary test piece. For this reason the use of the subsidiary specimen is subject to agreement. For the assessment of surface defects for instance the subsidiary specimens are extensively applied.

Both weld metal and heat affected zone are areas where low fracture toughness may occur. Weld metal is, however, the area where low toughness most frequently is found. Since the weld metal is an inhomogenous material, a considerable scatter in the individual test result is expected. To determine the critical COD-value to be used in the design curve, the common practice has been to test three specimens and select the lowest value as the critical.

The thickness of the specimens should always be equal to the maximum wall thickness, since the values obtained depend on the thickness. The testing temperature should be equal to the minimum service temperature.

Probabilistic fracture mechanics methods are likely to be applied more extensively to evaluate the risk of fracture. To obtain reliable input data, an increased number of specimens is desirable. In addition to requirements on a minimum value, the average value will probably be specified also.

8.6 Derivation of fracture toughness requirements and experience

The fracture toughness requirements would be specified based on an overall evaluation of design, materials, fabrication, quality control programs and in-service inspection programs. In derivation of the appropriate toughness level, there is to be some allowance for:

- Uncertainties in calculations of local stresses
- Stress raising effects due to geometrical imperfections/ tolerances
- Property variations occuring during manufacturing of materials as well as variations during prefabrication and assembly
- Existence of defects
- Capabilities to unambigiously detect, locate and size defects using intended NDT-equipment and NDT-procedures
- Possibility and probable conditions for inspection during fabrication and in-service
- Human errors

In general the tolerance to defects is to exceed the defects likely to exist or arise during the design life such that a brittle fracture would not be initiated. Accordingly, for fatigue loaded structures, a higher fracture toughness is specified than for only statically loaded components.

In practice fracture toughness requirements, if expressed in COD-values, would be calculated based on a defect tolerance parameter a_{max} in the range 8 to 12 mm. The minimum COD-value (mm), has been required in the range of:

	As welded	pwht
Special/critical joints	0.20 - 0.35	0.15 - 0.25
Primary joints	0.10 - 0.20	0.10 - 0.15

with testing at the minimum service temperature. These values are calculated from:

$$\bar{a}_{max} = \frac{\delta_c}{2\pi\, e_y \left(\frac{e_{tot}}{e_y} - 0.25\right)} \qquad \left(\text{for } \frac{e_{tot}}{e_y} > 0.5\right)$$

where δ_c = minimum COD-value

e_{tot} = total strain

$e_{tot} = e_{app} + e_{res}$ = applied + residual strain

e_y = yield strain of the material containing the flaw

The experience gained from application of fracture mechanics has shown that the weld metal constitutes the main fracture toughness problem. In Table 16 and 17 lower bound values for minimum single COD-values measured at maximum loads are given. Accordingly the results do not include unstable events associated with "pop-ins". The test assemblies have been made by manual metal arc welding in vertical position and submerged arc welding in horizontal position, using normal and higher strength steels of C-Mn, finegrain treated normalized type. Their CV-impact toughness had been guaranteed at -40 to -50°C. The results represent a population of appr. 460 weld metals and 230 HAZ COD-test specimens for the given welding positions and processes. Full thickness specimens have been used, and both txt and 2 txt specimens with standardized through thicknesss and surface notches are included.

Table 16: Lowest single COD's (mm) at max load for weld metals (0 to -10°C)

Condition Weld metal	Thickness Process	50 to 55	60	65	70	75	80	90	100
As welded	MMAW	0,08	0,09	-	0,08	0,10	0,07	-	0,04
	SAW	0,18	0,11	0,10	0,06	0,20	0,23	0,11	-
PWHT	MMAW	> 0,10	> 0,26	> 0,26	> 0,26	-	> 0,26	0,12	0,06
	SAW	> 0,26	> 0,26	0,07	0,15	0,14	0,16	> 0,26	> 0,26

(DnV data review per 1st. of February 1980, but excluding results from research project.)

Table 17: Lowest single COD's at max load for HAZ (0 to -10°C)

Condition	Thickness mm	50 to	60	70	75	80	90	100
	Process	55						
As welded	MMAW	0,15	0,35	0,35	0,35	0,35	-	-
	SAW	0,35	0,18	> 0,26	> 0,26	-	-	-
PWHT	MMAW	0,26	> 0,26	> 0,26	> 0,26	> 0,26	-	> 0,26
	SAW	0,20	0,20	> 0,26	-	-	-	0,24

Comparatively few unalloyed welding consumables can, when applied under practical conditions, give satisfactory fracture toughness without post weld heat treatment, and many weld metals are still inferior after such treatment. For important joints in heavy wall offshore structures, selection of welding consumables and welding procedure is therefore based upon fracture mechanics even for pwht parts.

9. MATERIAL REQUIREMENTS FOR SOME EXISTING AND PLANNED OFFSHORE STRUCTURES:

In the following paragraphs, some representative materials and material property requirements are presented and discussed.

The examples are representative for North Sea practice in recent years.

9.1 Materials specified for fixed offshore structures

Composition

Table 18 provides a list of chemical composition of steels that have been specified (Project specification) for fixed offshore structures in the North Sea. The values refer to maximum allowed contents. Where several values are given - the more stringent requirements refer to special structural steels and/or to thick material.

The special structural steels are typically specified to have lower carbon, phosphorus and sulfur contents. They are in general based on modified BS 4360 grade 50 D or DIN 17100 grade St 52-3 N. If a comparison is made to Table 5 and Fig. 5 which described goverment and classification society regulations, it is seen that in most cases the actual specifications are well below such requirements.

The heat treatment is in practically all cases normalizing. There is only one case where low-alloyed steel in the quenched and tempered condition has been used in the North Sea for fixed platforms. This was for the Maureen platform, where very thick sections were utilized (max 120 mm). A modified pressure vessel steel in QT-condition was specified as it had exellent fracture toughness. An extensive amount of back-up data existed for this steel. This steel was selected for chords and thick section nodes ($t > 100$ mm).

Strength and ductility

The typical strength and ductility properties have been

- yield strength min. 325 - 355 N/mm^2
- tensile strength 450 - 550 N/mm^2
- total elongtaion min 20 - 23%
- reduction of area Z direction: 20 to 35%

Typical Charpy impact energy requirements from some project specification are shown in Table 19 a-b.

TABLE 18 Materials specified for some fixed offshore units

PROJECT	C	Mn	Si	P	S	Cu	Mo	Ni	Cr	Nb	V	Ti	Al	N	CE	Classification
A (1981) Jacket	0,12	1,7	0,55	0,04	.008 .025	0,25	.08	.20	.10	.05	.05	.05	.08	.009	.40	Special
	0,18	1,6	0,5	0,05	.04	0,35		.04	.20						.43	Primary
B (1981) (Articulated tower)	0,10	1,6		.015	.008				.20	.009	.05	.04	.08			Special
	0,22	1,4	0,5 0,4			0,25 0,33	.08	.30								Primary
C (1981) Jacket	0,16	1,6	.35 .45	.03	01 .025	.35					.05	.05	.06	.012	(.02 Sn)	
	0,20	1,2		.04	.04											
North Cormorant (1980)	.15 .20 .18	1,5	0,45	0,03	.015 .03	to be analyzed				.04	.08		Al/N>2:1		0,41 0,45	Special Primary
D (1979) Jacket	0,20	1,6	0,50	.04	.01											Special
				.05	.04 .05	0,35	0,08	0,40	0,20	.05	.10	.05	.08	.009		Primary Secondary
Maureen	0,18	1,5	0,5	.04	.04											Special
QT steel A 533 B 1 mod.	.15	1,6	0,30	.035	.01		.45-.60	.40-.70		.05	.05					Special

TABLE: 19 a

TYPICAL REQUIREMENTS FOR SPECIAL STRUCTURAL STEELS SUPPLIED TO OFFSHORE PROJECTS

EXAMPLE	CARBON % (max)	CEV (max)	MINIMUM CHARPY V. NOTCH IMPACT VALUES LONGITUDINAL	TRANSVERSE	MINIMUM SHORT TRANSVERSE REDUCTION OF AREA % AVERAGE	INDIVIDUAL
A	.18	.43 (ladle)		35J at —40°C (25 ft/lbs at —40°F)	25	20
B	.18	.43 (ladle)	35J at —40°C (26 ft/lbs at —40°F)	24J at —40°C (18 ft/lbs at —40°F)	25	20
C	.16	.44 (product)	35J at —40°C (26 ft/lbs at —40 °F)		—	30
D	.16	.42 (ladle)	35J at —40°C (26 ft/lbs at —40°F)	35J at —40°C (26 ft/lbs at —40°F)	—	30
E	.18	.41 (ladle)	34J at —40°C (25 ft/lbs at —40 °F)		25	20
F	.20	.45 (product)		27J at —50°C (20 ft/lbs at —58°F)	35	25
G	.16	.40 (ladle)		35J at —50°C (26 ft/lbs at —58°F)	35	30
H	.16	.44 (product)		34J at —40°C (25 ft/lbs at —40°F)	—	30
I	.16	.40 (product)		35J at —40°C (26 ft/lbs at —40°F)	30	25
J	.16	.43 (ladle)		35J at —30°C (26 ft/lbs at —22°F)	25	20
K	.16	.40 (ladle)		35J at —50°C (26 ft/lbs at —58°F)	35	25

Plate Thickness 35 mm

Yield Strength 335 to 345 N/mm^2

Reference: BSC' publication "Plates for offshore"

TABLE 19 b

TYPICAL REQUIREMENTS FOR PRIMARY STRUCTURAL STEELS SUPPLIED TO OFFSHORE PROJECTS – PRIVATE SPECIFICATIONS

PROJECT	CARBON % (max)	CEV (max)	MINIMUM CHARPY V-NOTCH IMPACT VALUES	
			LONGITUDINAL	TRANSVERSE
A	.18	.43 (ladle)	35J at —30°C (26 ft/lbs at —22°F)	
B	.18	.43 (ladle)	35J at —40°C (26 ft/lbs at —40°F)	24J at —40°C (18 ft/lbs at —40°F)
C	.16	.44 (ladle)	35J at —40°C (26 ft/lbs at —40°F)	
D	.16	.42 (ladle)	35J at —40°C (26 ft/lbs at —40°F)	35J at —40°C (26 ft/lbs at —40°F)
E	.18	.41 (ladle)	34J at —40°C (25 ft/lbs at —40°F)	
F	.20	.43 (ladle)	41J at —20°C (20 ft/lbs at —4°F)	27J at —40°C (20 ft/lbs at —40°F)
G	.16	.40 (ladle)	35J at —50°C (26 ft/lbs at —58°F)	
H	.16	.44 (product)		34J at —40°C (25 ft/lbs at —40°F)
I	.16	.38 (ladle)		35J at —40°C (26 ft/lbs at —40°F)
J	.16	.43 (ladle)		35J at —40°C (26 ft/lbs at —40°F)
K	.16	.40 (ladle)	35J at —50°C (26 ft/lbs at —58°F)	
BS 4360:1979 Grade 50D	.18	.43 (ladle)	41J at —20°C (30 ft/lbs at —4°F) 27J at —30°C (20 ft/lbs at —22°F)	
BS 4360:1979 Grade 50E	.18	.43 (ladle)	47J at —30°C (35 ft/lbs at —22°F) 41J at —35°C (30 ft/lbs at —31°F) 27J at —50° C (20 ft/lbs at —58°F)	

Plate Thickness 35mm
Yield Strength 335-345 N/mm²

Reference: British Steel Corporation Publication: Plates for Offshore/Sept 81

In Table 20 are compiled data on characteristic requirements to chemical composition and mechanical properties for steels to a number of North Sea structures.

COMPARISON TABLE OF STEELS FOR OFFSHORE REQUIREMENTS

Basic standard		Offshore grades	Mechanical properties								Chemical composition in % (ladle)															Special additional requirements	Certificates acc. to DIN 50049
Std.	Grade		Refer thickness	Min yield point N/mm²	Tensile strength N/mm²	Elongation Min. %	Elongation Gauge length	Min. average impact energy absorption requirem. on ISO-V-Notch specimens Test temp. °C	Position of specimen	Joule	Heat treatment	C	Si	Mn	P	S	Cr	Ni	Mo	V	Nb	Ti	N	Cu	Al	Max Ew		
DIN 17100	R St. 37-2		16 (100)	235	360–440	23	5 d	+ 10°	L	27	U/N	Max 0,17			Max 0,050	Max 0,050												
DIN 17100	R St. 42-2		16 (100)	255	410–490	20	5 d	+ 20°	L	27	U/N	Max 0,23			Max 0,050	Max 0,050												
(DNV)	(NVA 27) (NVD 27) (NVE 27)	Mobil Grade 4		265	410–510	22	5 d	t ≤ 25 mm – 0° t – 25–50 – 20° t > 50 mm – 40°	T (L) T (L)	34 (51) 34 (51)	N or as Rolled	Max 0,18	0,10-0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,04	Max 0,04	Max 0,04	Max 0,009	Max 0,35	Max 0,08 Soluble	0,43 x)	See Spec. No. SP-JJ-001 Revision O	3.1.c.
(DNV)	(NVA 27) (NVD 27) (NVE 27)	Mobil Grade 6		265	410–510	22	5 d	t ≤ 25 mm t 25–50 – 0° t > 50 – 20°	Not Required T (L) T (L)	Not Req. 34 (51) 34 (51)		Max 0,18	0,10-0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,04	Max 0,04	Max 0,04	Max 0,009	Max 0,35	Max 0,08 Soluble	0,43 x)	See Spec. No. SP-JJ-001 Revision O	3.1.c.
(DIN 17100)	(R St. 37-2) or Equiv.	Mobil Grade 7	16 (100)	235	360–440	23	5 d	+ 10°	L	27	U/N	Max 0,17			Max 0,050	Max 0,050											See Spec. No. SP-JJ-001 Revision O	3.1.b.
DNV	NVA 27 NVD 27 NVE 27			265	400–510	22	5 d	– – 20° – 40°	Not Required L T L T	Not Req. 27 20 27 20		Max 0,18	0,10-0,50	0,9-1,6	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,05				Max 0,08 Soluble			
DNV	Shipbuilding Grade A				400–490	15-22	5 d.							≥ 2,5 x C	Max 0,05	Max 0,05											Rimming Steel Not Accepted. Ref. D.N.V.-Rules for Building and Classification of Steelships.	
(DIN 17100)	(R St. 37-2)	Amoco Type XXII	t ≤ 16 mm t 16–40 mm t > 40 mm	240 230 220	360–440	23	5 d	t ≤ 25,5 – 0° t 25,5–50 – 20° t > 50 mm – 40°	T T T	18 18 18	t > 13 mm N	Max 0,20	Max 0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,05	Max 0,05	Max 0,009	Max 0,35	Max 0,08 Total	0,43	See Spec. SP-S-200	3.1.c.
(DIN 17100)	(R St. 37-2)	Amoco Type XXII	t ≤ 16 mm t 16–40 mm t > 40 mm	240 230 220	360–440	23	5 d	t ≤ 25,5 mm t 25,5–50 – 0° t > 50 mm – 20°	Not Required T T	Not Req. 18 18	U	Max 0,20	Max 0,50	Max 1,60	Max 0,05	Max 0,05										0,43	See Spec. SP-S-200	

Basic standard		Offshore grades	Mechanical properties								Chemical composition in % (ladle)															Special additional requirements	Certificates acc. to DIN 50049
Std.	Grade		Refer thickness (max thickn.) mm	Min. point N/mm²	Tensile strength N/mm²	Elongation Min. %	Elongation Gauge length	Min. average impact energy absorption requirem. on ISO-V-Notch specimens Test temp. °C	Position of specimen	Joule	Heat treatment	C	Si	Mn	P	S	Cr	Ni	Mo	V	Nb	Ti	B/N	Cu	Al	Max Ew		
Din 17100	St 52-3		16 (50)	355	510–610	20	5 d	± 0°C – 20°	L L	27 27	U N	Max 0,20	Max 0,55	Max 1,50	Max 0,045	Max 0,045									x			
(DNV) (DNV)	(NVD 36) (NVE 36)	Mobil Grade 3 Primary Steel		355	510–610	21	Lo = 5,65 √S (A5) min.	t ≤ 25 – 0° 25–50 – 20° t > 50 – – 40°	T (L) T (L)	43 (65) 43 (65)	N or as Rolled	Max 0,18	0,10-0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,04	Max 0,04	Max 0,04	Max 0,009	Max 0,35	Max 0,08 Soluble	0,43 x)	See Spec. No. SP-JJ-001 Revision O	3.1.c.
DNV	NVD 36 NVE 36			355	490–610	21	Lo = 5,65 √S (A5) min.	– 20° – 40°	L T L T	34 24 34 24	N	Max 0,18	0,10-0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,05			Max 0,35	Max 0,08 Soluble		See D.N.V.-Rules for Building and Classification of Steelships	
(DNV)	(NVD 36)	Mobil Grade 5 Secondary Steel		355	510–610	21	Lo = 5,65 √S (A5) min.	t ≤ 25 – t – 25–50 – 0° t > 50 – 20°	Not Required T (L)	– 43 (65)	N or as rolled	Max 0,18	0,10 0,50	Max 1,60	Max 0,04	Max 0,04	Max 0,20	Max 0,40	Max 0,08	Max 0,04	Max 0,04	Max 0,04	Max 0,009	Max 0,35	Max 0,08 Soluble	0,43 x)	See Spec. No. SP-JJ-001 Revision O	3.1.c.
(DNV)	(NVE 36)	Mobil Grade I Z Special Steel		355	510–610	21	Lo = 5,65 √S (A5) min.	t ≤ 12 mm – 0° 12–25 – – 20° t > 25–50 – – 40° > 50 – – 40°	T (L) T (L)	43 (65) 43 (65)	N or as Rolled	Max 0,18	0,10-0,50	Max 1,80	0,04	0,008	Max 0,20	Max 0,40	Max 0,08	Max 0,04	Max 0,04	Max 0,04	Max 0,009	Max 0,35	Max 0,08 Soluble	0,43 x)	Through Thickness Properties Ultrasonic Testing. Reduction of Area. See Spec. No. SP-JJ-001 Revision O	3.1.c.
(DIN 17100)	(St. 52-3)	Amoco Grade XX	≤ 16 mm 16–30 mm 30–50 mm 50 mm	350 340 330 320	510–610	20	5 d	t – ≤ 25,5 mm – 0° 25,5–50 mm – – 20° t > 50 mm – 40°	T T T	24 24 24	N N N	Max 0,20	Max 0,50	Max 1,60	Max 0,040	Max 0,040	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,05	Max 0,05	Max 0,009	Max 0,35	Max 0,08 Total	0,43	See Spec. No. SP-S-200 Latest Rev.	3.1.c.
(DIN 17100)	(St. 52-3)	Amoco Grade XX0	t ≤ 40 mm 40–50 mm t > 50 mm	340 320 300	(t ≤ 40) 510–610 (t 40–50) 470–610 (t 50–75) 450–610	20	5 d	t ≤ 25,5 mm – 20° t – 25,5–50 – 40° t > 50 – 40°	T T T	24 24 24	N N N	Max 0,20	Max 0,50	Max 1,60	Max 0,020	Max 0,010	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,05	Max 0,05	Max 0,009	Max 0,35	Max 0,08		Through Thickness Properties Ultrasonic Testing. Reduction of Area. Latest Rev. See Spec. No. SP-S-200	3.1.c.
(DIN 17100) (Mobil Grade III)	(St. 52-3)	Fritenar 355 Offshore Z15	≤ 16 mm 16–30 mm 30–40 mm	355 345 335	510–610	23	5 d	t ≤ 50 mm – 20°	L	65	Special controlled rolling process	Max 0,16	0,10-0,50	Max 1,50	Max 0,030	Max 0,025	Max 0,20	Max 0,40	Max 0,08	Max 0,01	Max 0,04	Max 0,05	Max 0,009	Max 0,35	Max 0,08 Soluble	0,40 0,42	Min. 15 % reduction of area in Z direction	3.1.c.
(BS 4360)	(50 D)	Shell (U.K.) Ltd. Type I	< 19 mm t ≥ 19 ≤ 37 ≤ 75	355 345 335	Min. 490	20	5 d	Plates ≤ 25 mm – 20° Plates > 25 mm – 40° Rolled Sections Flange t ≤ 25 mm – 20° Flange t > 25 mm – 40°	L T L L	41 27 27 27	t > 19 mm N	Max 0,20	Max 0,45	Max 1,50	Max 0,03	Max 0,03				Max 0,08	Max 0,04		Max 0,012			0,43 (t = 63–75 0,44)	Ultrasonic Testing of Plates According to DD 21, Grades CcE See Spec. No. 6703-00-2-850-000	
(BS 4360)	(50 D or Equ. Std.)	Phillips Petr. Company (British Sector)	t ≤ 30 t > 30 ≤ 50 t > 50	340 330 320	500–620	20	5 d	t ≤ 20 mm – 20° t > 20 mm – 40°	L L	35 35		Max 0,18	0,10-0,50	Max 1,50	Max 0,04	Max 0,04				Max 0,08	Max 0,05				X	0,43	See Spec. No. P/L/S 201 (S 205)	3.1.b.
(DIN 17100)	(St. 52-3)	Elf Aquit.		353	510–608	21		– 20° – 20°	T L	24 35		Max 0,20	Max 0,50	Max 1,45	Max 0,040	Max 0,035	Max 0,20	Max 0,40	Max 0,08	Max 0,10	Max 0,050	Max 0,05	Max 0,009	Max 0,30	Max 0,055 Total	0,45	Ultrasonic Testing of Plates See Spec. NE 623010000 005	3.1.c.
BS 4360	50 B 50 C 50 D		16 (100) 16 (100) 16 (63)	355 355 355	500–620 500–620 500–620	20 20 20	5 d 5 d 5 d	– – 15° – 30°	– L L	– 27 27	N N N	Max 0,20 0,20 0,18	Max 0,50 0,50 0,10-0,50	Max 1,50 1,50 1,50	Max 0,050 0,050 0,040	Max 0,050 0,050 0,040					Max 0,10 0,10 0,10							
STEW 089	TT St. E 36		35 (150)	355	490–630	22	5 d	– 50° – 20°	L T	27 27	N N	Max 0,18	0,10-0,50	0,90-1,80	Max 0,030	Max 0,030				Min. 0,05	Min. 0,02				Min. 0,015			
ASTM A5 72	50		51	345	Min. 450	18	8"				N	Max 0,23	0,15-0,30	Max 1,35	Max 0,04	Max 0,05				0,01 0,15	0,005 0,05							

Reference: Aspelin-Stormbul publication: "Offshore - a field for experts".

Case structure I: NORTH CORMORANT

The North Cormorant platform was installed in UK waters of appr. 160 m in 1981. It has the combined function of drilling, production and quarter. The installation is operated by Shell Expro UK, and has been designed in CJB & Earl and Wright, London.

The total steel weight of the platform with equipment and piles is about 25500 tons. Oil production started 14 Feb. 1982. This is one of the largest steel jackets yet installed in the North Sea.

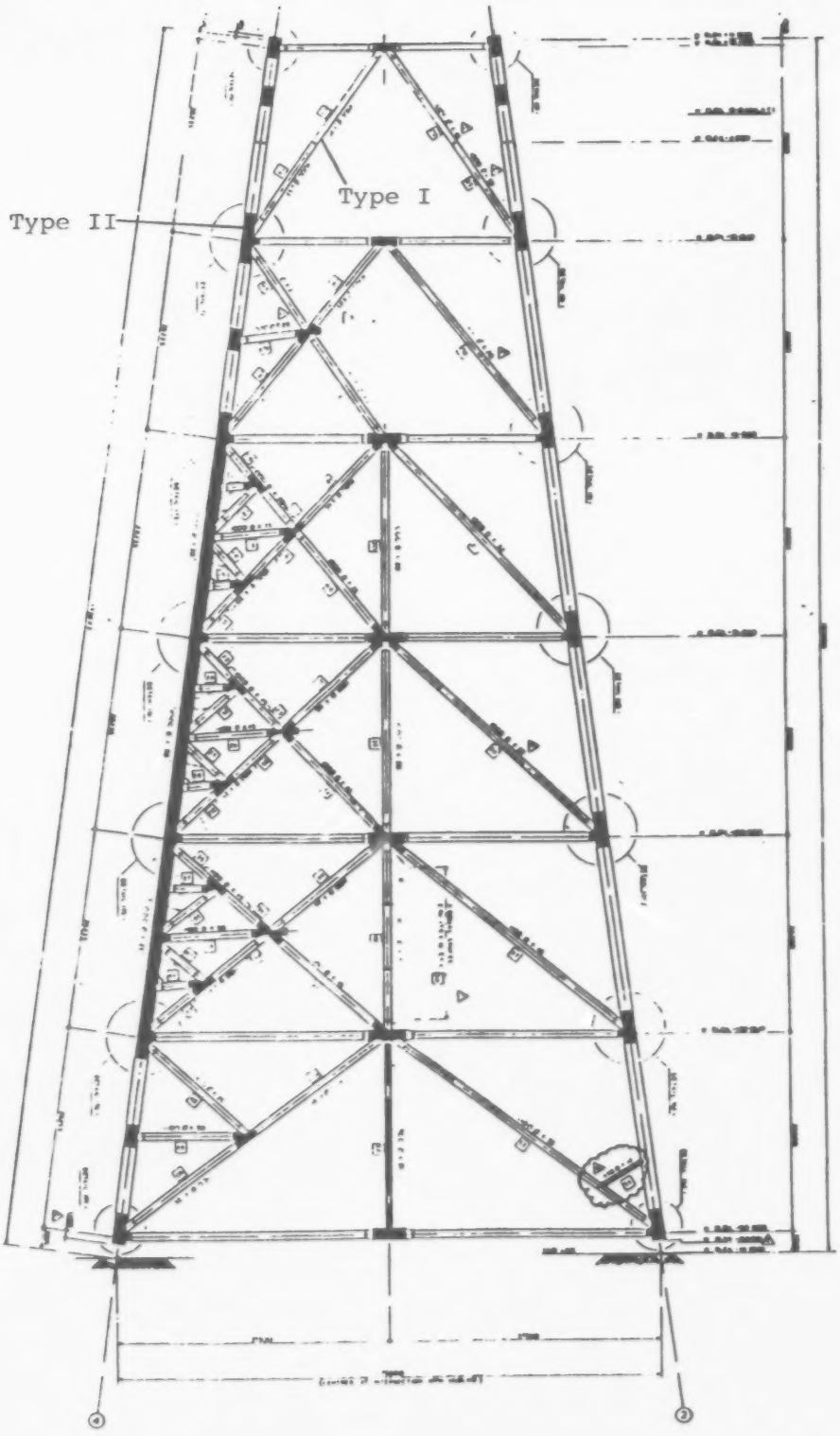
The jacket is schematically shown in fig. 9. Main members were specified to be of Type I and II steels (corresponding to primary and special structural steel as per DnV definition). The respective application in the jacket is shown as "white" and "black" members on the figure. Maximum thickness is 100 mm.

These steel types were modification of BS 4360 - 50 D as regards chemical composition and mechanical properties.

Principal steel requirements - North Cormorant specification

Type I	Fully killed, fine grain treated, normalized for t > 19 mm 0.20 C, 1.5 Mn, 0.45 Si, 0.03 P, 0.03 S, 0.012 N, 0.04 Nb, 0.08 V CE (prod.) < 0.43 for t < 75 mm, 0.45 for t = 75 to 100 mm Y.S. : 355 - 335 MPa, UTS > 490, after simulated pwht for t > 35 mm t < 25 mm : CVL/27 J, -20°C t > 25 mm : CVT/41 J, -40°C Ultrasonic testing of plates to BS DD 21, grade C and E
Type II	Fully killed, fine grain treated, low S and P, vacuum degassed LD-steel with Z-properties. Composition: As for type I except 0.015 S, CE < 0.45 for t < 75 and 0.47 for t > 75. Y.S.: 345 to 325 MPa, UTS > 510 - 490 MPa, simulated pwht for t > 37 mm CVT/-50°C: 27 J, RAZ > 35%, UTS (Z) > 0.8 UTS (Y) Ultrasonic testing of plates to BS DD 21 - Grade A1

Fig. 9 North Cormorant jacket



Principal welding/fabrication requirements - mechanical properties

Construction standard	:	AWS D.1.1 - 1978 with suppl. requirement to welding procedure and welder qualification, inspection and testing.
Fracture toughness	:	See Table 21
Max hardness	:	300 HV 10
PWHT	:	See Table 21
Welding consumables	:	LH-types
Cold forming	:	Max 5%, > 5 then stress relief

The criteria for COD-testing and post weld heat treatment was derived on the following bases:

a) Welded joints in plates, tubulars and nodal assemblies where the thickness exceeds 40 mm shall require p.w.h.t. unless this requirement is negated by procedural qualification of COD values for as-welded joints.

b) Welded joints in plates, tubulars and nodal assemblies where the thickness of either part joined exceeds 50 mm (splash zone and air) and 63.5 mm (submerged zone) shall require p.w.h.t. However, where one member is tapered to meet the other as a butt weld, the thickness shall be that at the weld line.

c) p.w.h.t on nodes shall be carried out following complete assembly of the node.

d) An individual structural weld or a node containing any weld which on structural analysis is shown to exceed a maximum pseudo-elastic design stress of 465 N/mm^2 under any load case shall require p.w.h.t.

e) Welds in type I and II steels not subject to p.w.h.t. under d) in the thickness range 40 mm to 50 mm for the splash zone and air, and 40 mm to 63.5 mm in the submerged zone shall be left as-welded if the COD requirements below are attained in all the relevant welding procedures for both weld metal and heat affected zone.

f) COD testing to BS DD19 is to be carried out on weldments in the as-welded condition at minus 10°C to qualify both for splash zone and air, and 0°C to qualify for submerged zones. Test pieces should be of the preferred test piece geometry and the method of calculation of COD shall be in accordance with clause 7.2.2 of DD19 (the Wells method).

g) COD testing shall be carried out to qualify all procedures for weldments subject to post weld heat treatment.

h) COD testing shall be carried out for manual or semi-automatic welding in vertical (3G) position to qualify for all positions within the procedure limitations. Submerged arc welds shall be qualified in the flat (1G) position. Both weld metal and HAZ shall be tested and in addition further test plates shall be prepared representing maximum and minimum heat inputs under that welding procedure.

TABLE 21

NORTH CORMORANT - FRACTURE TOUGHNESS AND PWHT CRITERIA FOR MAIN MEMBERS

To qualify	as welded or p.w.h.t.	zone of structure	thickness range (mm)	Weld metal + haz C.O.D.			Weld metal + haz Charpy (average)		Weld root charpy (average)	
				min average mm	indiv min	temp °C	Energy	temp °C	energy	temp °C
All welds within steels type I and type II	as-welded	submerged	0<t≤12.7	none	none	-	34J	-20°C	34J	-20°C
			12.7<t≤25	none	none	-	34J	-25°C	34J	-25°C
			25 <t≤40	none	none	-	34J	-25°C	34J	-25°C
			40<t≤63.5	0.26	0.21	0°C	34J	-30°C	34J	-30°C
	as-welded	s.z.a.	0<t≤12.7	none	none	-	34J	-20°C	34J	-20°C
			12.7<t≤25	none	none	-	34J	-25°C	34J	-25°C
			25 <t≤40	none	none	-	34J	-30°C	34J	-30°C
			40<t≤50	0.26	0.21	-10°C	34J	-40°C	34J	-30°C
All welds within nodes (including cans, barrels, stubs, cones, stiffeners and diaphragms)	p.w.h.t.	submerged and s.z.a.	0<t≤12.7	none	-	0°C(sub)	34J	0°C	34J	0°C
			12.7<t≤25	none	-	-10°C	34J	-20°C	34J	-20°C
			25 <t≤40	none	-	(sza)	34J	-20°C	34J	-20°C
			40<t≤90	0.18	0.14		34J	-20°C	34J	-20°C
Tubular butt welds	p.w.h.t.	submerged and s.z.a.	0<t≤12.7	none		0°C(sub)	34J	0°C	34J	0°C
			12.7<t≤25	none			34J	-20°C	34J	-20°C
			25 <t≤40	none		-10°C	34J	-20°C	34J	-20°C
			40<t≤100	0.13	0.10	(sza)	34J	-20°C	34J	-20°C

TABLE 3.2 FRACTURE TOUGHNESS REQUIREMENTS

Notes:

1. sub = submerged = welds in structure below minus 3m L.A.T.
   s.z.a. = splashzone and air = welds in structure above minus 3m L.A.T.
   a-w = as welded
   p.w.h.t. = post weld heat treated

2. Secondary structural steel indicates welded assemblies exclusively consisting of steel tubulars to sections 2.4 and 2.5 and/or rolled sections to sections 2.7 and 2.8

Case structure II: MAUREEN

The Maureen platform will be a combined drilling production, storage and quarter installation. The platform is operated by Phillips Petroleum Company and has been designed by Tecnomare. The water depth is 96 m. It is now under construction and planned installed in 1982. The substructure is schematically shown in fig. 10.

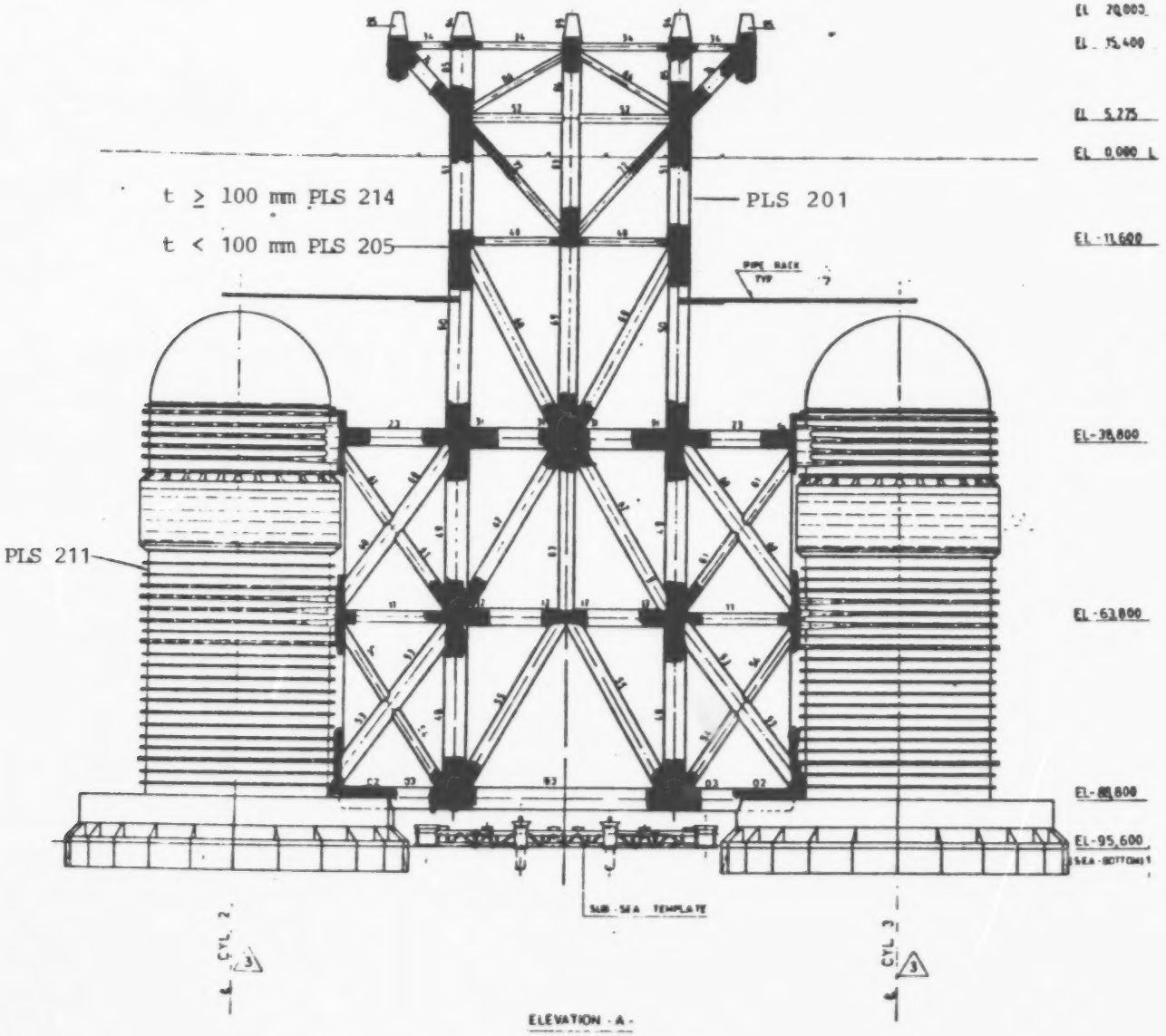


Fig. 10 Maureen platform

The platform has many particular features, and this also concerns materials and fabrication; e.g.:

- o Wall thicknesses up to 120 mm
- o Use of nuclear grade steel, A 533 Gr B modified for the thickest node members (t > 100 mm)
- o Very large and complex pre-fabricated nodes
- o Steel storage tanks designed for sour service using blistering resistant steel
- o Steel weight is 70.000 tons (substructure, deck and equipment)

Five main steel types well specified for the following application:

P/L/S 201	Primary members: Braces, legs, base external stiffeners of tanks
P/L/S 205	Special members: Chord tubulars, cruciform joints/base (t < 100 mm)
P/L/S 211	Primary parts: storage tanks
P/L/S 212	Special parts: storage tanks
P/L/S 214	Special members: Chord tubulars, main attachments of lattice to storage tanks walls (> 100 mm)

Other steel types were also used, e.g. seamless tubes, beams, sections where the material properties are in principal the same as for plates used in members of same classification.

The COD-requirements imposed by the Certifying Authority were derived on the following basis:

The COD-values were calculated by the procedure given in BS PD 6493: "Guidance for derivation of acceptable levels for defects in fusion welded joints. The defect tolerance parameter a_{max} was selected to be 12 and 8 mm for single side and double side welded joints respectively. The applied strain was taken to be the maximum estimated to arise in the typical joints. The residual strain was taken to be of yield stress magnitude in welds of complex nodes. For circumferential welds a 2/3 factor was used on residual stresses for evaluation of defects parallel to the weld. In stress relieved conditions residual stresses were assumed relaxed by 90%. The following minimum COD-values (mm) were specified:

Classification	Primary member circ. seam		Special members and nodes	
Final condition	Single side	Double side	Double side	Single side
As welded or local pwht.	0.21	0.14	0.26	0.35
Furnace pwth.	0.12	0.06	0.14	0.21

The testing carried out according to BS DD-19/1972 was performed at 0°C for submerged parts while -10°C for the others.

Principal requirements for these steels were:

P/L/S201	BS 4360-50D modified: 0.05 Nb, 0.08 V, CE < 0.43 ladle Y.S. = 350 - 330 MPa t > 20 mm: 3.6 kgm CVL/-20°C t < 20 mm: 3.6 kgm CVL/-40°C t > 50 mm: Simulated pwht of test sample
P/L/S 205	As P/L/S 201 with additional RAZ > 20% and CVT of 2.4 kgm at same temperatures. UT: STE 072-77 Class 3
P/L/S 212	As P/L/S 205 with additional: 0.009 S, 0.39 CE Blistering resistance to be documented Tensile properties: As for P/L/S 205
P/L/S 211	BS 4360 - 40E modified: 0.009 S, 0.05 Nb, 0.08 V, 0.39 CE Blistering resistance to be documented t < 25 mm: 2.8 kgm CVL/0°C t > 25 mm: 2.8 kgm CVL/-20°C t > 50 mm: 2.8 kgm CVL/-40°C UT: STE 072-69 Class 3
P/L/S 214	ASTM A533-77 Type B/Cl 1 modified: 0.15 C, 0.01 S, 0.05 Nb, 0.07 V V + Nb < 0.07 Y.S.: 310 MPa; UTS: 470 MPa after double pwht CVL/-50°C: 3.6 kgm, CVT: 2.7 kgm RAZ: 20% UT : BS DD21 Class A1

The principal welding/fabrication requirement to mechanical properties were:

Reference standard: AWS D.1.1 for lattice structure
BS 5500 and NACE FM-01(80) for storage tank
CV-test of weld metal + HAZ: As for base metal
Hardness: Max 280 HV 10 except 240 for storage tanks.
COD-tests of weld metal for t > 50 mm
COD-tests of HAZ for t > 100 mm
PWHT: As DoE requirements with allowance to raise thickness limit based on COD-tests.
Cold def.: Max 5%, stress relief if gtr.

9.2 Materials specified for mobile offshore structures

Table 10 provides a list of some extra high strength steels applied for mobile drilling rigs of the jack-up type structure. These steels are used in the quenched and tempered or precipitation hardened condition. Material thickness ranges generally from 20 to 40 mm, except for the jack-up rack where thickness up to 150 mm may occur.

A particular feature is the relatively high Ni-content. The role of Ni is to promote low temperature ductility of the steels in order to compensate for the strengthening effect imposed by addition of Cr, V and Mo.

It is worth noticing that the carbon content in these steels is relatively low compared to materials described earlier. This is essential because brittle martensite is to be avoided as a result of quenching and also to improve the weldability of these high strength steels.

Typically mechanical property requirements are

- yield strength 450 - 690 N/mm^2
- tensile strength 550 - 930 N/mm^2

Impact energy requirements are typically about

40 Joules at -40°C (longitudinal specimens - plates)

COD testing is seldom required for mobile offshore structures, since material thicknesses are rarely great due to the high strength of the materials. In connection with rack-plates for jack-ups where material thickness of 130-140 mm are encountered, fracture mechanics has been required. For other special members such as cast nodes, fracture mechanics testing has also been applied.

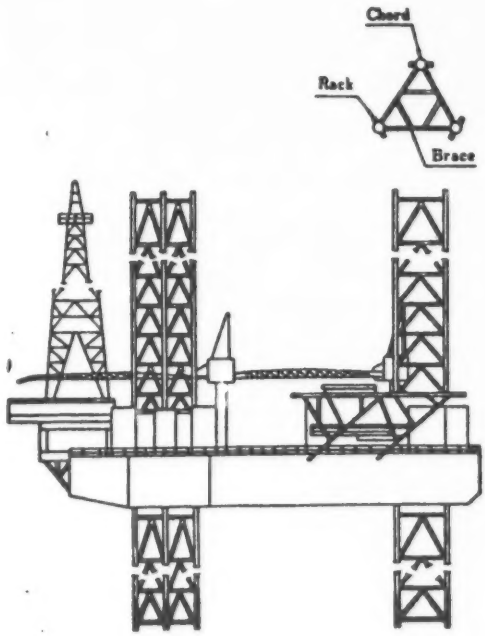
A few examples of the use of extra high strength steels in mobile rigs are indicated in the following.

Table 10 (Mobile Units)

	Manufacturer	C	Mn	Si	P	S	Cu	Mo	Ni	Cr	Nb	V	Ti	Al	N	Strength
			Min.													
			Max.													
1975	Marcel Freres SA															640 N/mm^2
ETA	Rive deGier							0.15-	4.2-	.20		0.02-				64 J (-40°C)
jackup	rack plates	0.15	0.2-0.6	0.2	0.02	.015		0.35	4.8	-.45		0.10				(740-840 N/mm^2)
	QT or norm/temp															
	(140 mm)															
Sambre et Meuse, Cast nodes		0.10-	0.35-0.70	0.10-	< 0.03	<0.020	0.3	0.3-	2.3-	0.8-	0.06			0.10	0.01	689 N/mm^2, 793 N/mm^2
		0.20		0.50				0.6	2.7	1.2						34 J (-40°C)
1980	AG der Dillinger	0.04-	0.9-	0.2-					0.8-		.04-			.02-		490 N/mm^2
T2005C	Hüttenwerke				.025	.025	1			0 40						40 J (-40°C)
jackup	CR + precip	0.09	1.9	0.6			1.5		1.2		.10			.08		(610-760 N/mm^2)
	hardened plates															
1980	Pont A Mousson SA	.05	1.7	.10				0.20	2.50		.05			.01		650 N/mm^2 / 735 N/mm^2
T2005C	Centrifugally cast				.020	.012										40 J (-40°C)
jackup	tubes	.10	2.3	.40				0.40	3.50		.08			.05	0.020	
	QT															
	Creuset-Loire	.19	0.8	.15	.030	.025		0.45	1.2	1.25	0.05	0.10				32 J 685 N/mm^2
T2005C	Superelso 700 TR		1.5	.50												(-40°C) 789-930 N/mm
jackup	plates															
	QT															

Case structure III: JACKUP RIG T2005C

Figure 11 shows the T2005C jackup rig designed by CFEM, Paris, for water depth of max 90 m, and with a minimum design temperature of -15°C. Several extra high strength materials are utilized in construction of the leg structure.



Centrifugally cast tubes of OD 800 mm, made in 2,5-3,5% Ni-steel with low C-content 0,05-0,10% have been used in the chords. The alloy is further characterized by low S (.01%). The heat treatment is quenching and tempering to achieve a yield strength of min. 650 N/mm^2. The specified CV-impact requirement is 40 Joules at -40°C. Chords associated with the racks are manufactured from plate with specified carbon content max. 0,19% and max, 1,2% Ni, and is in the quenched and tempered condition. The yield strength 685 N/mm^2 is somewhat higher than for the centrifugally cast chords.

The horizontal braces in the lower part of the leg are 16" seamless tubes (API 5LU-X100) in the quenched and tempered condition. The yield strength 660 N/mm^2 is obtained in this relatively low alloyed steel by addition of vanadium 0,11 -0,15%. Towards the upper part of the structure the normal braces are 15" (X 70) with a lower yield strength of 450 N/mm^2 obtained by normalizing and tempering of C-Mn steel.

The diagonal braces in the upper part of the leg are of the same material but smaller dimension 14". The diagonal braces (14") in the lower part (U 85) are quenched and tempered to a yield strength of 590 N/mm^2. Both the Mn and V content are slightly lower than for the horizontal bracing.

The small 8" inner bracing (X 52) is conventional C-Mn fine grain treated steel in the normalized condition with yield strengths in the range 355 N/mm^2.

The impact energy requirement for all bracing is indicated in the table below:

		Yield strength	Impact energy
Horizontal bracing	upper structure	450 N/mm^2	40 J (-30°C)
	lower structure	660 N/mm^2	40 J (-40°C)
Diagonal bracing	upper structure	450 N/mm^2	40 J (-30°C)
	lower structure	590 N/mm^2	40 J (-40°C)
Inner bracing		355 N/mm^2	34 J (-20°C)

The hull structure is made of ship grade steel, see Table 2 a.

Case structure IV: Semisubmersible of Pacesetter design

Figure 12 shows the Pacesetter type rig which is a column stabilized semi-submersible drilling unit designed by Fried + Goldman, Houston. The rig has class for "world wide operations", i.e. min. design temperature of -15°C. The rig consists of two lower hulls supporting six columns and an elevated main deck.

The 35' columns are designed with 14 - 19 mm thick shell plating of grade D steel. This is a normal strength steel, see Table 2. The Charpy impact test requirement is 27 Joule longitudinal and 20 Joule transverse with impact testing at -10°C.

The horizontal and diagonal bracing (6' - 9') including the nodes are of higher strength steel grade EH 36. This requires Charpy testing at -40°C with 34 Joule (L) and 24 Joule (T). The yield strength minimum is 355 N/mm^2. The main girders for the deck structure is designed with this grade. In connections where high restraints or stresses occur in the thickness direction, steels with guaranteed Z-ductility are used. The hull structure is made of grade A steel for thicknesses up to 12.5 mm. Thicker plates are required impact tested.

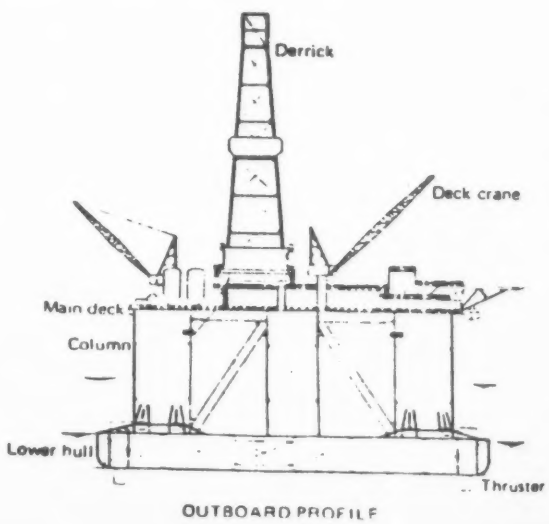


Fig. 12 Pacesetter type rig

10. SUMMARY

This report has reviewed requirements for structural steel and weldments in mobile and fixed offshore platforms. The review is based on regulatory guidelines enforced by The U.S. Geological Surveys, The Norwegian Petroleum Directorate, The Department of Energy, UK as well as the rules issued by the Classification Socities Det norske Veritas, Lloyds Register, American Bureau of Shipping, Germanische Lloyds and Bureau Veritas. The regulations and rules are compared with current offshore practice as reflected by the company specifications of major operators, and by the most referenced industrial standards.

Special attention has been given to specifications pertaining to North Sea structures.

The implications of imposting the material requirements of present regulations, rules and standard established for temperatures down to -15 to -20°C are commented upon. Alternative design solutions or approaches seems to be necessary for lower temperatures.

REFERENCES

Dept. of Energy, U.K.	Offshore Installations: Guidance on design and construction.
Det norske Veritas	Rules for the design, construction and inspection of offshore structures 1977
Det norske Veritas	Rules for classification of mobile offshore units 1981
American Petroleum Institute	API RP 2A Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms 1981
Germanisher Lloyd	Rules for the Construction and Inspection of Offshore Installations 1976
Bureau Veritas	Rules and Regulations for the Construction and Classification of Offshore Platforms 1975
US Geol. Survey	Regulation for Verification of the Structural Integrity of OCS Platforms
Lloyds Register	Rules for the Construction and Classification of Mobile Offshore Units 1972
American Bureau of Shipping	Mobile Offshore Drilling Units 1980 (Rules for Building and Classing)
Nippon Kaiji Kyokai	Mobile Offshore Units, Part B and P (1978)
Climatic Atlas	Outer continental shelf water and coastal regions of Alaska, vol III
US Dept. of Interiors	Bureau of Land Management
Glenn and Associates	Wave height distribution in Gulf of Campeche and offshore Louisiana (1977)
Various specifications and DnV reports	

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APPENDIX "A"

STATEMENT OF WORK

The contractor will undertake the following:

1) Compile the relevant materials and welding specifications recommendations or guidelines used by various Governments (including U.K., Norway, U.S.A.), the classification societies (Lloyds, ABS, Bureau Veritas, Det Norske Veritas, Nippon Kaiji Kyokai, Polski Rejestr Statkow, Germanischer Lloyd, Registra Italiano Novale, U.S.S.R. Register of Shipping) and other organizations (e.g. API) for use in the construction of offshore structures. Specifications include steelmaking practice, heat treatment, chemical analyses, tensile properties and fracture properties. The contractor will define the procedures used in determining these properties, with particular emphasis on the fracture properties (i.e., Charpy V-notch, COD, J int, etc.).

2) Provide information regarding the location in typical structures where the various steels are used. This information will be summarized in the form of simplified diagrams showing the location in the structure of the various types of steels.

3) Particular attention will be given to any mention in the specifications or regulations to service temperature or minimum service temperature and the relationship between this temperature and the grade of steel, the fracture properties of the steel, and the thickness of the steel.

4) Provide information on the specifications for the steels actually used in the construction of fixed and floating structures designed for hydrocarbon exploration and exploitation in the North Sea or other cold water environments. These specifications will include the properties discussed above and any additional specifications (such as through thickness properties). This information will be based on the detailed specifications used in the construction of at least 4 structures (2 floating and 2 fixed) built since 1978. The specific structures used for examples will be decided on after consultation with the EMR Scientific Authority.

5) At the conclusion of the contract the contractor will present the essential results in a seminar at the Physical Metallurgy Research Laboratories. One copy of all slides or other visual aids used will be supplied to PMRL for their retention.

6) The contractor will supply 100 copies of the final report.

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QUALITY

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